DIY INFRASTRUCTURE

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DIY INFRASTRUCTURE

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SUMMARY

This document investigates a set of projects I call DIY Infrastructure, in which designers are building alternative infrastructural systems. Through these projects, new actors–often non-experts–reveal and re-imagine long-established social and technological relationships which were previously off limits to them. These projects are significant to the study of design and digital media for the following reasons:

First, they detail a new area of design. The designers of DIY infrastructure present an expansion of the scope of design coupled with a nuanced and almost paradoxical understanding of infrastructure as an intractable and exceedingly complex problem. At the same time, their work reveals the extensive social and political effects of existing design decisions–the far-reaching consequences of the design decisions which formed existing infrastructure. These decisions are in play across a variety of scales of time and space, affecting individual bodies as much as continental ecosystems, and shaping personal behavior as much as global commerce and trade.

Second, they expand the scope of digital media studies. Digital media studies often overlook infrastructure, in spite of their interdependence. Digital media are involved in areas including the control and monitoring of the electrical system, the treatment and movement of water and sewage, and the routing of freight through intermodal shipping systems. The study of DIY infrastructure design, and infrastructure more broadly, exposes the role of digital media in shaping these overlooked aspects of modern life. There is an invisible relationship between digital media, infrastructure, and political authority, and it

includes the interdependence of infrastructure and the contingent nature of our ongoing reliance on these complex sociotechnical systems.

For example, Cloacina is the project of two activists developing a new municipal waste disposal system in which a decentralized networked system significantly lessens the amount of water used in processing human waste. Another project, Feral Trade Courier, employs the sort of shipping database we might associate with FedEx or UPS to facilitate an alternative shipping infrastructure, in which volunteers transport goods in an ad hoc freight network.

I begin by surveying and defining DIY practice, delineating the properties of infrastructure, and determining the ways that those properties and practices can be augmented or diminished by the affordances of digital media. Next, I review the attributes that these DIY infrastructure projects share before revealing their significance through in-depth case studies. Finally, each of these case studies highlights a particular lesson from DIY infrastructure. Feral Trade Courier exposes the role of the social and the subjective in the design of logistics systems. Village Telco and Fluid Nexus show us that the relationship between established infrastructure and DIY infrastructure can be both complementary and antagonistic. Cloacina provides us an example of a way that DIY infrastructure might scale up and effect lasting sociotechnical change.

Whether motivated to reveal or overcome dependence on infrastructure, address flaws in its design, or correct externalities generated by its use, new designers have begun to engage with the problem of infrastructure in new ways. This document analyzes these design projects through a series of case studies, synthesizing a new perspective on the study of infrastructure through design and on the scope of digital media research along the way.

1. INTRODUCTION

Figure 1. Wikileaks and critical infrastructure.

(http://www.domusweb.it/en/architecture/open-source-design-02-wikileaks-guidecritical-infrastructure/ accessed Oct. 20, 2012)

In the June 2011 issue of the design and architecture journal Domus, architectural critic Geoff Manaugh discusses a classified cable sent by U.S. Secretary of State Clinton in February of 2009, and subsequently released to the public through Wikileaks. The cable describes “critical infrastructure and key resources located abroad.”

Figure 2. List of critical infrastructure sites.

(http://www.domusweb.it/en/architecture/open-source-design-02-wikileaks-guidecritical-infrastructure/ accessed Oct. 20, 2012)

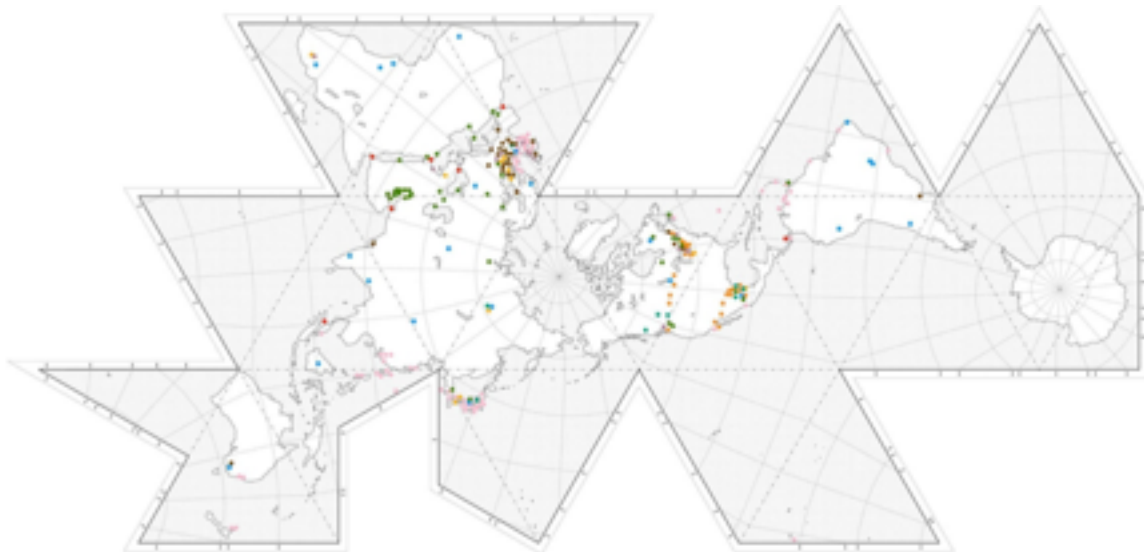

Figure 3. Map of critical infrastructure sites.

(http://www.domusweb.it/en/architecture/open-source-design-02-wikileaks-guidecritical-infrastructure/ accessed Oct. 20, 2012)

These critical infrastructures and key resources are divided into sectors, including energy, agriculture, banking and finance, drinking water and water treatment systems, public health, nuclear reactors and “critical manufacturing[1].” We see them displayed on a map in figure 2, above, and in figure 3, below, as a geographically sorted list. All of these locations, objects, or services, the cable explains, “if destroyed, disrupted or exploited, would likely have an immediate and deleterious effect on the United States[2].” Indeed, there is no back up: several sites are highlighted as “irreplaceable[3].”

[1] Geoff Manaugh, “Open Source Design 02: Wikileaks Guide/Critical Infrastructure,” *Domus* 948 (2011), accessed October 20, 2012, http://www.domusweb.it/en/architecture/open-source-design-02-wikileaks-guidecritical-infrastructure/.

[2] Ibid.

[3] Ibid.

Despite the fact that this cable was classified, the necessity of infrastructure to our way of life and the degree to which infrastructural connections are global are hardly secrets. Recent events, whether deliberate, accidental, or outside of human control, have disrupted infrastructure, and the lives of people who depend on it. For example, on April 9, 2009, someone deliberately cut through a cluster of fiber optic cable beneath San Jose, California, resulting in the disruption of emergency communications including those of local hospitals[4]. Some municipal authorities found themselves unable to function normally, until they enlisted the help of local ham radio operators, part of a long-standing do it yourself (DIY) subculture, who were able to intervene and provide an alternate system of communication when the established communication systems of professionals and experts were disabled. This chain of events not only illustrates the potential fragility of infrastructure, and also highlights the possibility of DIY responses to its disruption operating in the void left by traditional political and institutional responsibilities.

Whether motivated to reveal or overcome dependence on infrastructure, address flaws in its design, or correct externalities generated by its use, new designers have begun to engage with the problem of infrastructure in new ways. This document analyzes these design projects through a series of case studies, synthesizing a new perspective on the study of infrastructure through design and on the scope of digital media research along the way.

Because these designers are often non-experts, or at least unaffiliated with the interests which have typically been responsible for designing and deploying infrastructure, I

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[4] Karen de Sá, "The hunt is on for fiber-optic cable saboteur," *The San Jose Mercury News*, April 11, 2009, accessed Oct. 24, 2012, http://www.mercurynews.com/centralcoast/ci_12121118.

refer to their work as DIY infrastructure. While there may be some historical examples of non-experts involved in developing infrastructure, notably ham radio, DIY infrastructure projects are different in that they are the work of designers responding to existing infrastructure and not just tinkerers attempting to address their own needs. These projects should not be dismissed out of hand because they have yet to scale up and acquire a large user base, or because many cases they are still within the prototyping stage; Of course, that is where design takes place. Moreover, DIY infrastructure projects are significant in that designers are attempting to build complete infrastructural systems, not just their components. For example, in the project Cloacina, a DIY sanitation infrastructure project discussed at length in a later section, designers are not just concerned with building toilets and sinks; the design of those objects is just a means to a redesign of all of the interrelated components and systems of sanitation infrastructure.

DIY Infrastructure and Design Theories and Practices

These DIY infrastructure projects are a new phenomenon and they raise significant questions. While the remainder of this document examines the space of this new relationship between designers and infrastructure, describing infrastructure and its connections to various issues in turn, our immediate concern is with understanding how the design of DIY infrastructure fits in (and fails to fit in) with existing conceptions of design and design practices. Of course, in some cases, a failure to fit in may suggest that a conception of design needs rethinking, or illuminate important differences between the design of DIY Infrastructure and other design practices. In other cases, a correspondence between DIY infrastructure projects and existing conceptions and practices of design may situate these projects more securely within the domain of design studies.

DIY Infrastructure and Existing Design Practices

The DIY infrastructure projects discussed in this document share some similarities with existing design practices. Its worthwhile to note some of those similarities, as well as to point out some differences. Those differences allow us to see how DIY infrastructure is something unique within the realm of design.

First, DIY infrastructure projects have some similarity to relational aesthetics or relational art. Relational aesthetics is a phrase coined by Nicolas Bourriaud to refer to art which takes human interaction as its subject: "the role of artworks is no longer to form imaginary and utopian realities, but to actually be ways of living and models of action within the existing real, whatever scale chosen by the artist.[5]" The terms relational aesthetics or relational art have been used to refer to a variety of contemporary works of art in which an artist or design facilitates shared activities.

While DIY Infrastructure is tied to human interactions and the social, and some of its designers, notably Kate Rich from Feral Trade, self-identify as artists, the ultimate goal of DIY infrastructure projects is the paradoxical one of exposing infrastructure's workings while creating new infrastructure. Social interaction, the province of relational art, is not the end goal. DIY infrastructure designers are attempting to build functioning sociotechnical systems, and those systems include but extend beyond the social.

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[5] Nicolas Bourriaud, *Relational Aesthetics* (Dijon: Les presses du réel, 1998), 113.

Next, we can see some similarity between DIY infrastructure and Speculative or Critical Design, from their history in architecture all the way through the work of Dunne and Raby and Bill Gaver. Speculative design adopts an explicitly critical and experimental stance which extends into the domain of emerging technology products and services including robotics and biotechnology. For example, Dunne and Raby's designs mimic modernist lamps, coffee tables, or other minimalist modern product designs, but these forms veil a larger critique of consumerist values[6]. However, a critical design approach is not an attempt to develop usable products. Instead, its "products" are tools for cultivating an informed critique of the exchange between our lives and the lives of design objects. In contrast, I'm arguing that while DIY infrastructure projects adopt a similar critical stance, and may also explore emerging technologies, they are attempts to build something that is actually usable.

Finally, there is a relationship between DIY infrastructure and material participation. In her book Material Participation, Nortje Marres argues that materials are participants in political dialogue, and she uses this idea to describe a set of political activities, such as the ability of design objects to mediate engagement in political affairs[7]. Im arguing that through these DIY Infrastructure projects, we see material participation as an emerging practice of design.

Design typically has an expectation of rote functionalism. That expectation can stifle design innovation. DIY infrastructure designers adopt some of the practices of criti-

[6] Anthony Dunne and Fiona Raby, *Design Noir: The Secret Life of Electronic Objects* (Boston: Birkhäuser, 2001).

[7] Noortje Marres, *Material Participation: Technology, the Environment and Everyday Publics* (New York: Palgrave MacMillan, 2012), 8-13.

cal design, relational art and material participation to avoid this expectation of rote functionalism. This allows them a more comfortable space for experimentation. Later in this document I discuss that space for experimentation in terms of the multi-level perspective on technological change, but for now it is important to note its ties to other design practices. In the next section I provide another set of comparisons and contrasts, this time between DIY infrastructure and existing conceptions of design.

DIY Infrastructure and Existing Conceptions of Design

In Herbert Simon's canonical book *The Sciences of the Artificial* [8], he argues that design is concerned with the contingent–not what is, but what could be[9]. Simon describes design as the process of changing an existing state into a preferred state, of arranging components and organizing procedures to attain goals. [10] Within Simon's conception of design, design involves a choice among alternatives. The search space is defined by the constraints of the outer environment, then by the parameters of the object to be designed–the goals or purpose for which its components will be organized. While these initial principles are difficult to dispute without context–identifying design as concerned with what is preferred as opposed to what exists is almost tautological–most criticism of Simon's definition involves a variety of exceptions to his rules. In many cases things like existing and preferred states are variable, and themselves contingent. Thus, they can be difficult to identify with any degree of rigor.

[8] Herbert Simon, *The Sciences of the Artificial* (Cambridge: The MIT Press, 1996).

[9] Ibid. 117.

[10] Ibid. 115, 117.

In refining his explanation of the design process, Simon makes a distinction between what he terms the outer environment–the constraints of the world in which the object of design exists, and the inner environment–the parameters defining the designed object. Simon uses the example of planning a diet to explain this: food prices and the nutritional qualities of foods constitute the outer environment, while constraints such as a caloric limit or quotas of particular quantities of vitamins constitute the inner environment. [11]

Simon felt that design could be formalized into a science–one that used concepts of utility to proceduralize the process of choosing among possible arrangements of components. [12] This science of design would be an "analytic, partly formalizable, partly empirical, teachable doctrine about the design process." [13] We can, as Simon suggests, envision a procedure for determining a diet by narrowing the search space of the inner environment.

Simon admits that this example of choosing a diet is simple. In fact, he benefits from providing such a simple, and thus more easily understandable, example. He does believe, however, that the method he uses the example to suggest can scale up to handle more complex design problems, and distinguishes between well-defined and ill-defined problems. He argues that ill-defined problems can be turned into well-defined ones in order to be addressed by designers.

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[11] Ibid. 116-117.

[12] Ibid. 118.

[13] Ibid. 54.

The work of DIY infrastructure designers does not fit neatly into Simon's model. Simon briefly raises the example of road construction to call attention to the need for more explicit consideration for the costs of design, [14] and we can use a similar example to discuss the difficulty of using Simon's model to consider DIY infrastructure design. Simon suggests approaching problems by examining the parameters of the inner environment and the constraints of the outer environment. Within DIY infrastructure design, these are hard to distinguish from each other and they may even influence each other reciprocally. Investigating either of these environments may create unanticipated changes in the other. For example, in deciding the best place to construct a new road, the parameters, corresponding to Simon's inner environment, may change the constraints, or outer environment: the placement of the road may affect factors such as traffic, local and regional economic patterns, and ecological patterns. Through this sort of feedback, the solution forces a reformation of the design problem.

In fact, an inability of the designer to see the whole picture–an object of design so complex as to be unidentifiable when viewed at certain scales–may even be one of the characteristics of DIY infrastructure projects. In searching for a more appropriate place to locate DIY infrastructure within design theory, we turn to wicked problems.

[14] Ibid. 125.

Infrastructure and Wicked Problems

In 1973 Horst Rittel and Melvin Webber coined the phrase "wicked problem" in their article "Dilemmas in a General Theory of Planning." [15] Wicked problems are "[a] class of social system problems which are ill-formulated, where the information is confusing, where there are many clients and decision makers with conflicting values, and where the ramifications in the whole system are thoroughly confusing." [16] This identification of Wicked Problems, and the associated list of their properties, provides a strong contrast to Simon's assertion that problem solving can be completely systematized and rationalized. Rittel and Webber view wicked problems as distinct "from problems in the natural sciences, which are definable and separable and may have solutions that are findable." [17] In contrast, wicked problems may "rely upon elusive political judgment for resolution." [18]

Richard Coyne describes Rittel and Webber as joining "a chorus of dissenters" from Simon's "attempted rationalization," claiming that they "argued persuasively, and in terms understandable to the systematizers, that the design process, and any other professional task, is only very poorly explained in terms of goal setting, constraints, rules and state-space search." [19] The design of infrastructure is much more of a wicked problem than it is a scientific process of sorting constraints and determining a single point of op-

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[15] Horst Rittel and Melvin Webber, "Dilemmas in a General Theory of Planning," *Policy Sciences* 4, no. 2 (1973): 155-169.

[16] Ibid.

[17] Ibid. 160.

[18] Ibid.

[19] Richard Coyne, "Wicked Problems Revisited," *Design Studies* 26, no. 1 (2005): 6.

timality. Infrastructure is massively complex, involves large numbers of stakeholders, and–because of its interconnection–can generate unanticipated effects in unexpected domains.

There are several properties of Wicked Problems described by Rittel and Webber. Many of them have explicit ties to infrastructure, a quintessential wicked problem. The designers of DIY infrastructure are knowingly and deliberately entering into this wicked problem space. We can see this when we take a closer look at some of the attributes Rittel and Webber advance, including:

An impossibility of determining all possible solutions or methods: there is no way to know if all of the possible solutions to a wicked problem have been determined and tested. [20] Designers can only act in the hopes that they have made the most exhaustive search of the design space possible.

A difficulty of formulation: in order to adequately formulate a wicked problem, a complete understanding of all of the solutions to that problem is necessary. Obviously, it is difficult to determine solutions to an unidentified or incompletely identified problem. [21] As I will discuss in the next section, one of the properties of infrastructure is a reach or scope which makes it extremely difficult to isolate as an object of study. [22]

A difficulty of testing solutions: solutions cannot be appraised until all of their resultant effects have been determined. According to Rittel and Webber "we have no way of

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[20] Horst Rittel and Melvin Webber, "Dilemmas in a General Theory of Planning," *Policy Sciences* 4, no. 2 (1973): 164.

[21] Ibid. 160.

[22] Susan Leigh Star, "The Ethnography of Infrastructure," *American Behavioral Scientist* 43, no. 3 (1999): 381, doi:10.1177/00027649921955326.

tracing all the waves through all the affected lives ahead of time within a limited time span."[23] Put another way, and using infrastructure as an example, the effects of decisions made by the designers of infrastructure are so far reaching that they are difficult to anticipate. Few of the parties involved in the design and implementation of the American interstate highway system could have predicted all of its social and economic effects–positive or negative–much less effects like heat islands, which distort regional weather patterns.

An inability to learn by trial and error without significant risk: in words that speak directly to infrastructure's exemplary status as a wicked problem, Rittel and Webber explain that "[l]arge public-works are effectively irreversible, and the consequences they generate have long half-lives."[24] DIY infrastructure projects are in part a response to the alleged irreversibility of large-scale public works and their consequences. In some cases, this can make the designers of DIY infrastructure seem quixotic. It is one thing to reinvent the wheel; it is another thing to reinvent the entire transportation system.

Wicked Problems in Design Thinking

In his article "Wicked Problems in Design Thinking," Richard Buchanan draws upon Simon's work and upon Rittel and Webber's conception of wicked problems to provide a new definition for design. He describes design as the "new liberal art of technological culture," involving "Intentional operations carried out in the sciences, the arts of produc-

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[23] Horst Rittel and Melvin Webber, "Dilemmas in a General Theory of Planning," *Policy Sciences* 4, no. 2 (1973): 163.

[24] Ibid.

tion, or social and political action," and "the conception and planning of the artificial." [25] This definition is not directly at odds with Simon's, but it is much more inclusive, and its inclusion of the idea of wicked problems makes it more suited to a discussion of DIY infrastructure and its designers.

Buchanan argues that design is limited by indeterminacy, and that "there are no definitive conditions or limits to design problems."[28] According to Buchanan, "design problems are indeterminate and wicked because design has no special subject matter on its own apart from what a designer conceives it to be."[29] Buchanan believes that design "is manifested in the plan for every new product. The plan is an argument, reflecting the deliberations of designers and their efforts to integrate knowledge in new ways, suited to specific circumstances and needs."[30] This may be true, but if it is to describe the design of DIY infrastructure, it needs to go further.

So, Simon's conception of the design process as an iterative narrowing of a search space is problematic with regard to infrastructure because of the difficulty of defining an inner and outer environment. Looking at infrastructure in terms of wicked problems is less problematic, but while that may help us accurately define or categorize some of the things that motivate DIY infrastructure designers, it is less helpful in helping us understand how DIY infrastructure can effect change.

With that in mind, I focus on two areas of research from outside of design studies to help explain the design of DIY infrastructure. The first is a distinction between two types

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[25] Richard Buchanan,"Wicked Problems in Design Thinking," *Design Issues* 8, no. 2 (1992): 5-21.

of resilience–most notably identified by ecological economist C.S. Holling. In contrast to Simon's idea that design is a search for a single point of optimality, Holling discusses situations in which systems have multiple points of equilibrium and therefore do not have a single point of optimality. The second area that I am attempting to bring into the fold of design studies is that of the multi-level perspective on sociotechnical transitions. This perspective is an attempt to isolate the factors that cause sociotechnical change. For example, the multilevel perspective may be used to explain why a certain technology–such as gasoline powered automobiles–becomes dominant while others (e.g. steam or electrically powered automobiles) do not. I discuss these ideas of multiple points of equilibrium and sociotechnical transitions within the context of case studies in later chapters. These ideas from outside of design studies can help us understand DIY infrastructure design. Within the realm of design studies, Dorst's concept of design paradoxes is more useful.

Design Paradoxes

In a Summer 2006 article in Design Issues, Kees Dorst reviewed some of the criticism of Simon's conception of design, and added his own:

> "Creative design seems more to be a matter of developing and refining together both the formulation of a problem and ideas for a solution, with constant iteration of analysis, synthesis, and evaluation processes between the two notional design 'spaces'—problem space and solution space. In creative design, the de-

> signer is seeking to generate a matching problem-solution pair, through a coevolution of the problem and the solution."

This conception of design, that of a designer making iterative loops through the spaces of problem formation and solutions, has more in common with the work of DIY infrastructure designers, but it still does not allow us to see whole picture of their endeavors. Dorst dispenses with the idea of design problems and offers the concept of design paradoxes in its stead. He argues that the designer has to transcend or connect different discourses, and that that process requires a designer to understand but avoid the potentially contradictory ways of thinking embodied in those discourses. He proposes that "the central notions that make up the paradoxes the designers are dealing with indeed are meant to shift in the course of creating a solution.[26]" This idea of design paradoxes gets us out of problem space, the identification of design with problem solving, and moves us into a space that is better able to accept the experimentation of DIY infrastructure design.

Categorical Arbitrage

Dorst's concept of design paradoxes matches up well with DIY infrastructure design. For example, with Cloacina, the DIY sanitation project discussed at length in chapter eight, you see this movement between discourses, a sort of categorical arbitrage in which the designers shift between defining themselves and their work as a public awareness problem, an emergency sanitation preparedness project, and a start up company building

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[26] Kees Dorst, "Design Problems and Design Paradoxes," *Design Issues* 22, no. 3, (Summer 2006): 10, 16.

portable toilets. With Feral Trade, the DIY shipping infrastructure project discussed in chapter six, you see this same categorical arbitrage in the designer's self-identification as both an artist and a trader, and in her shifting identification of her work as both something new and as something documenting a long standing practice.

It is this sort of forum shopping, in which DIY infrastructure designers are constantly looking for existing domains to associate their work with, that speaks to what I identify as the key implication of these DIY infrastructure projects: a radical difference in scale. Its impossible for these designers to fully associate their work with existing domains or practices because the focus of DIY infrastructure is much larger and exceeds that of those domains. Unlike most design endeavors, DIY infrastructure is not just an argument or plan for the use or implementation of a product or service; it is in many ways a plan for the life of the user.

Infrastructure is not just a series of systems that we depend on in our day to day lives. It is also something that shapes our lives; that regulates them *through* design. The designers discussed in this document are not ignorant of this. In fact, many of their designs are motivated by it. I discuss the properties of infrastructure that inform this motivation in a later section. First, in the next section, I define DIY and discuss DIY practice and the way it relates to DIY infrastructure.

2. WHAT IS DIY?

Design and use are also blurred in DIY practice, where design is no longer the province of experts. DIY involves the creative endeavors of non-experts in areas which are currently or were once considered the job of paid technical professionals such as carpenters and electricians. For example, if I replace the fixtures in my bathroom and repaint my bathroom walls, I am undertaking tasks that were once the exclusive domain of professional plumbers and painters. DIY activities have increased as they have been augmented by digital tools which support them directly and social computing technologies which support the exchange of information about them. I can go online and watch video tutorials showing me how to construct DIY drone aircraft, and I can post questions or share knowledge in online forums about a variety of DIY activities.

According to Kuznetsov and Paulos of the Human-Computer Interaction Institute at Carnegie Mellon University, DIY includes "any creation, modification or repair of objects without the aid of paid professionals […] most of DIY culture is not motivated by commercial purposes."[27] According to design historian Paul Atkinson, DIY is "a more democratic design process of self-driven, self-directed amateur design and production activity carried out more closely to the end user of the goods created [28]." Both of these

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[27] Stacey Kuznetsov and Eric Paulos, "Rise of the Expert Amateur: DIY Projects, Communities, and Cultures," in *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries*, NordiCHI '10 (New York: Association for Computing Machinery, 2010), 1.

[28] Paul Atkinson, "Do It Yourself: Democracy and Design," *Journal of Design History* 19, no. 1 (2006): 1.

definitions apply to DIY infrastructure designers. They create and modify infrastructural systems and components that would normally fall within the domain of highly specialized professionals. They are not primarily motivated by commercial gain. Their work is self-directed and they interact with infrastructure in ways that its users typically do not.

Of course, the distinction between professionals and DIY practitioners has not always been easy to make, but it has blurred even more since the First World War. As Atkinson argues, "Part of the sustained growth of DIY as a leisure activity from the 1960s onwards may be attributable, at least in part, to a gradual de-skilling of the processes involved, reducing much of Do It Yourself to a case of self assembly and finishing [29]." If we examine what were considered DIY activities in the 1935 book *The Practical Man's Book of Things to Make and Do*, we see "activities that lack of time alone is likely to prevent many people from undertaking today. Manufacturers and retail chains alike have worked to develop and promote easier methods of producing the results which once required so much dedicated input through new materials and kits of parts. [30]"

The affordances of infrastructure have changed the necessity of DIY practice even as they have increased it. Participation in DIY practice is possible because of the leisure time made available by the infrastructures supporting modern life. People preserve blueberries for amusement and pleasure, while they once did so for survival. According to Atkinson, "the economics of global-scale mass production have put first world consumers in the position where necessities such as cooked food, clothes and furniture can often be purchased for less than it would cost to purchase the raw materials to produce them them-

[29] Ibid. 5.

[30] Ibid.

selves—even if they did possess the relevant skills to do so. In these circumstances it is no surprise that DIY today is often not seen to be a necessity of any kind, and can only make sense if it is seen instead as a leisure pursuit or lifestyle choice. [31]"

With regards to DIY infrastructure, it's important to note that DIY activities have long been enabled by new technologies, and in some cases DIY practitioners utilizing those technologies have been viewed as a threat by entrenched professional interests. Examples predate the advent of personal computing, and include mixed paint in cans and the invention of the paint roller in the 1950s being seen as a threat to professionals, and complaints from British Electrical Development Associations and the UK Home Office about the danger posed to the public by articles on home electrical repairs.[32]

Digital Media Augment DIY Practice

More recently, digital media such as "social computing, online sharing tools, and other HCI collaboration technologies" have increased participation in DIY endeavors by providing newer and often more powerful digital tools and new ways to share information. [33] Kuznetsov and Paulos argue that "An emerging body of tools allows enthusiasts to collaboratively critique, brainstorm and troubleshoot their work, often in real-time. This accessibility and decentralization has enabled large communities to form around the

[31] Ibid.

[32] Boswell, cited in D. Johnson, "The History and Development of Do-It-Yourself," in *Conference on Twentieth Century Design History* op. cit., p. 68, cited in Ibid., 6.

[33] Stacey Kuznetsov and Eric Paulos, "Rise of the Expert Amateur: DIY Projects, Communities, and Cultures," in *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries*, NordiCHI '10 (New York: Association for Computing Machinery, 2010), 1.

transfer of DIY information, attracting individuals who are curious, passionate and/or heavily involved in DIY work.[34]"

These descriptions, however, *do not go far enough* in recalling the relationship between DIY, innovation, and tools. After all, without the results of earlier DIY practices by groups such as the Homebrew Computer Club, or the developers of the Apache http server, many of the tools Kuznetsov and Paulos mention would not exist. *DIY endeavors do not just benefit from technological change, they initiate it.*

The words "do it yourself" should not be read to indicate that these projects are the work of designers working alone or without collaborators, nor should they be read to indicate that DIY infrastructure involves the creation of objects or services which are inferior to their non-DIY counterparts. I also chose the term DIY Infrastructure to highlight a paradoxical aspect of these projects. Infrastructure is a shared resource, and so the "I", or individual in DIY, is a conceptual mismatch. It's also important to note that the designers I'll discuss today aren't acting in isolation, that they exist as part of different communities that have formed around different issues. Instead, DIY infrastructure indicates an expanding sense of agency: designers are developing a new relationship with the problem of infrastructure. In order to understand this new relationship, it is necessary to look more closely at infrastructure and its properties.

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[34] Stacey Kuznetsov and Eric Paulos, "Rise of the Expert Amateur: DIY Projects, Communities, and Cultures," in *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries*, NordiCHI '10 (New York: Association for Computing Machinery, 2010), 1.

3. ON INFRASTRUCTURE

When tasked with defining infrastructure, Paul Edwards–director of University of Michigan's Science, Technology & Society Program who has written extensively on the subject–suggests a simple and helpful heuristic: when confronted with the panoply "of systems and institutions referenced by the term, perhaps 'infrastructure' is best defined negatively, as those systems without which contemporary societies cannot function.[35]" According to this rubric, we can evaluate infrastructure by asking ourselves how we would get along without the technologies dependent on it. For example, it is easy to argue that the electrical system is infrastructure because its affordances–including our being able to see after the sun goes down and our being able to refrigerate food so that it does not spoil–inform our survival.

What if we pose the same question regarding the internet? Our response in 1992 may have been as quizzical as our response today would be imperative. The loss of services such as banking, access to medical information, VoIP service, web-based maps and navigation services, and many business-to-business transactions would have profound effects. Manuel Castells' 2000 statement "the Internet, and its diverse range of applications, is the communication fabric of our lives, for work, for personal connection, for information, for

[35] Paul N. Edwards, "Infrastructure and Modernity: Force, Time, and Social Organization in the History of Sociotechnical Systems." In *Modernity and Technology,* eds. Thomas J. Misa, Philip Brey and Andrew Feenberg (Cambridge: The MIT Press, 2003), 187.

entertainment, for public services, for politics, and for religion [36]" now seems like a statement of the obvious. As more services become contingent upon the internet, they also become contingent upon the infrastructures on which it relies.

With infrastructure, frequency of use breeds habit, and habit breeds reliance. This becomes more apparent during an infrastructural disruption, when infrastructures which were invisible or taken for granted are brought to light. For example, in investigating media dependency during large-scale disruptions, the sociologist Wilson Lowrey found that "[t]he greater the perception of threat from the events of September 11, the greater the dependency on mass media."[37]

The Conditions of Modernity

If–to paraphrase Edwards–we consider infrastructure as that which modern life is contingent upon, we find that it is difficult to separate the importance of infrastructure from that of the practices and transactions it enables. According to Edwards, infrastructures "co-construct–the condition of modernity." Put another way, "[to] be modern is to live within and by means of infrastructures." For example, without infrastructures, we would be without computers, the internet, air travel, air conditioning, running water, highways, and all of the other technologies which invisibly support our day-to-day lives. Further, infrastructures work across scales of time, space, social organization, and force

[36] Manuel Castells, The Rise of the Network Society: *The Information Age: Economy, Society and Culture*, 2nd ed. (Hoboken: Wiley-Blackwell, 2009), xxvi.

[37] Wilson Lowrey, "Media Dependency During a Large-Scale Social Disruption: The Case of September 11," in *Mass Communication and Society* 7, no.3 (2004): 345-349.

to create what Edwards calls the "foundation of modern social worlds [38]." Without these "connective tissues […] and circulatory systems of modernity," such as transportation, electrical power, and waste disposal, those among us without particular merit badges might find ourselves in an uncomfortable position–bearing a remarkable similarity to the people we deem primitive. [39]

Flows of Material and Information

It becomes difficult to distinguish between what has been called variously a globalized or network society, and the technical infrastructures of information and communication technologies and "just-in-time" supply chains which support its characteristic transactions. Moreover, it is difficult to distinguish between the material and informational elements of those systems. In many ways "globalization" is just a word describing the broader social and economic effects of infrastructures such as telephony and intermodal shipping.

Published in 1997, the findings of the first United States Presidential commission on Critical Infrastructure Protection defined infrastructure as "a network of independent, mostly privately-owned, man-made systems and processes that function collaboratively and synergistically to produce and distribute a continuous flow of essential goods and

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[38] Paul N. Edwards, "Infrastructure and Modernity: Force, Time, and Social Organization in the History of Sociotechnical Systems." In *Modernity and Technology,* eds. Thomas J. Misa, Philip Brey and Andrew Feenberg (Cambridge: The MIT Press, 2003), 185.

[39] Ibid.

services. [40]" Edwards puts this into context: "The free-marketeering sloganism of this definition should not distract our attention from its key concept: flow. [41]"

Flow refers to the constant movement of matter, energy, and information necessary to–and facilitated by–infrastructure. According to Geographers Stephen Graham and Simon Marvin, "all infrastructure networks require movement to occur, whether this is in the form of flows of energy, water, people, freight or electronic impulses. [42]" For example, "[w]ater and energy services consist of one-way flows between production and consumption nodes. Transportation and telecommunications are much more complex, involving a multiplicity of interactive flows between many nodes which are both consumers and producers of communication. [43]" So, flow is vital to both infrastructure and the transactions and distributions that it enables.

Of course, "flow" is integral to many conceptions of the mutually generating nature of the social and technological spheres of our lives. Edwards raises several examples; these include Anthony Giddens' argument of "space-time distanciation," in which he refers to the increasing importance of remote and mediated communication; [44] David Harvey's theory of "space/time compression," which refers to the alterations in the relationship between space and time wrought by technologies such as transportation and tele-

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[40] United States, President's Commission on Critical Infrastructure Protection, *Critical foundations: protecting America's infrastructures : the report of the President's Commission on Critical Infrastructure Protection* (Washington, DC: The Commission, Supt. of Docs., U.S. G.P.O., distributor, 1997), ix, 3.

[41] Paul N. Edwards, "Infrastructure and Modernity: Force, Time, and Social Organization in the History of Sociotechnical Systems," in *Modernity and Technology,* eds. Thomas J. Misa, Philip Brey and Andrew Feenberg (Cambridge: The MIT Press, 2003), 187.

[42] Stephen Graham and Simon Marvin, *Telecommunications and the City*: *Electronic Spaces, Urban Places* (New York: Routledge, 1996), 281.

[43] Ibid.

[44] Anthony Giddens, "Time-Space Distanciation and the Generation of Power," in *A Contemporary Critique of Historical Materialism: Power, Property and the State* (New York: Macmillan, 1981), 90–108.

communication; [45] and Paul Virilio's characterization of the effects of telecommunication on modern life as a "Dictatorship of Speed. [46]" All of these are discussions of the effects of information infrastructure. The most effective articulation of the concept of flow is in the work of Manuel Castells, which Edwards describes as "fully characterizing the close interplay among sociotechnical infrastructures and the grand patterns of twentieth-century cultural, economic, psychological, and historical change." Castells refers to this interplay as the "space of flows".

Put simply, this is the idea that information infrastructure is not only a conduit of "information products and processes, but also of the global organization of material production and distribution." [47] Information infrastructure is not just the means by which information is created or procedures by which that information is processed–these things ultimately shape the material world. The intangible realm of information shapes the tangible realm of physical objects and transactions.

The "space of flows" describes "the co-evolution of industrial capitalism and its infrastructures." [48] The development of infrastructure has been influenced by the modes of exchange and distribution it has enabled, and those modes of exchange and distribution have affected infrastructure in turn. According to Edwards, this reveals a "powerful, if

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[45] David Harvey, *The Condition of Postmodernity: An Enquiry into the Origins of Cultural Change* (Oxford: Blackwell, 1990).

[46] Paul Virilio,"Speed and Information: Cyberspace Alarm!" *Ctheory*, trans. Patrice Riemens, last modified August 27, 1995, http://www.ctheory.net/articles.aspx?id=72.

[47] Paul N. Edwards, "Infrastructure and Modernity: Force, Time, and Social Organization in the History of Sociotechnical Systems," in *Modernity and Technology,* eds. Thomas J. Misa, Philip Brey and Andrew Feenberg (Cambridge: The MIT Press, 2003), 187.

[48] Ibid.

never entirely determining, functional logic."[49] Furthermore, the reciprocal developmental relationship between infrastructure and industrial capitalism makes it more difficult to isolate infrastructure as an object of study. On top of all of these considerations, infrastructure modulates our daily lived experiences, something I discuss at length in the next section.

Modulation and Variability of the Natural Environment

Of course, regardless of any informational properties it might have, all infrastructure is ultimately a system for overcoming or modulating the natural environment. Examples of this include the ability to "regulate indoor temperatures, have light whenever and wherever we want it, draw unlimited clean water from the tap, and buy fresh fruits and vegetables in the middle of winter.[50]" Edwards adds the following items to that list: the ability to "work, play, and sleep on schedules we design, to communicate instantaneously with others almost regardless of their physical location, and to go wherever we want at speeds far beyond the human body's walking pace[51]." Furthermore, "Infrastructures constitute an artificial environment, channeling and/or reproducing those properties of the natural environment that we find most useful and comfortable; providing others that the

[49] Ibid.

[50] David Nye, "Narratives and Spaces: Technology and the Construction of American Culture," quoted in Edwards, "Infrastructure and Modernity," 188-189.

[51] Ibid.

natural environment cannot; and eliminating features we find dangerous, uncomfortable, or merely inconvenient.” [52]

This modulation is increasingly affected by the affordances of digital media, as we see in Edwards’ example of the regulation of indoor temperatures [53]. While simple thermostats turn HVAC systems on or off when a pre-determined temperature threshold is reached, more elaborate models may call upon the affordances of digital media (which I discuss at length in the next section). [54] For example, the encyclopedic affordance of digital media allows the recording of temperature fluctuations, while procedural affordance allows the interpretation of those fluctuations before turning on or off the heat. Thermostats such as the Nest, pictured below, are able to record a user’s attempts to change the temperature, compare it to the current temperature, and then estimate and create an ideal temperature for that user.

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[52] Paul N. Edwards, “Infrastructure and Modernity: Force, Time, and Social Organization in the History of Sociotechnical Systems,” in *Modernity and Technology,* eds. Thomas J. Misa, Philip Brey and Andrew Feenberg (Cambridge: The MIT Press, 2003), 188-189.

[53] Ibid.

[54] Janet Murray, *Inventing the Medium* (Cambridge: The MIT Press, 2011), 56.

Figure 4. Nest thermostat.

(http://www.earthtimes.org/newsimage/thermo-learning_2510.jpg, acccessed Sept. 26, 2012)

As the affordances of digital media allow us to create devices with these properties, they have two contradictory effects: first, they may make infrastructure more opaque. For example, it may be easier for an amateur handyman to correct a problem with a conventional mechanical thermostat than with a Nest. Conversely, it is these same affordances of digital media that are empowering DIY infrastructure designers. Without access to digital tools such as CAD software, sensors, or informational resources available online, the collaboration and prototyping that DIY infrastructure projects require would be difficult to facilitate.

Infrastructures are contingent on assumptions about the variability of the natural environment. [55] As recent history has made clear, events such as earthquakes and tsunamis can create devastating disruptions to interconnected infrastructural systems. [56] Our reliance on the artificial nature provided by infrastructure is such that "'natural disaster' really refers primarily to this relationship between natural events and infrastructures [57]." Outside of immediate physical injury, the profound effects of a natural disaster come from hospitals and water treatment facilities with no electricity and roads rendered impassible to emergency vehicles and trucks carrying food, potable water, and medical supplies.

Most importantly, we are being nagged by the realization that the relationship between infrastructure and the natural environment is reciprocal; for example, the byproducts of our fossil-fuel based transportation and energy generation infrastructure are altering the climate. In turn, the changing climate changes the environment in which infrastructures are situated. In turn, it affects their operation. Continuing with the previous example, the changes to the climate wrought by the byproducts of our transportation and energy generation infrastructure may "increase in the frequency of severe weather events. [58]" Those events then disrupt transportation infrastructure. For example, severe weather can force airports to close, or take oil refineries offline.

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[55] Paul N. Edwards, "Infrastructure and Modernity: Force, Time, and Social Organization in the History of Sociotechnical Systems," in *Modernity and Technology,* eds. Thomas J. Misa, Philip Brey and Andrew Feenberg (Cambridge: The MIT Press, 2003), 188-189.

[56] Ibid. 193.

[57] Ibid. 194.

[58] Ibid. 193.

We view these severe weather events and natural disasters as tragedies, and they unveil the contingent and perhaps unsustainable nature of our way of life. According to Edwards, “infrastructures fail precisely because their developers approach nature as orderly, dependable, and separable from society and technology–an understanding that is in fact a chief characteristic of modern life–within-infrastructures. Yet nature recalcitrantly refuses to agree to this modernist settlement […] Thus modernity can also be depicted as a condition of systemic vulnerability. [59]”

The designers behind DIY infrastructure projects are aware of infrastructure’s role as a substrate of modernity and of its role in maintaining flows of material and information and in modulating our natural environment. One key facet of DIY infrastructure is that it reveals the role that infrastructure plays in our daily lives. In order to understand this revelation, it is necessary to articulate infrastructure’s properties–something I do in the next section. After that, I discuss some key terms from the study of infrastructure before undertaking an analysis of the relationships between digital media, infrastructure and political authority.

A thorough discussion of DIY infrastructure demands a clear formulation of the properties of all infrastructure. To that end, I call on Susan Leigh Star’s germinal article “The Ethnography of Infrastructure.” In the following table, I revisit her rubric–sometimes stopping to give examples or to comment on the political nature of each of the characteristics she discusses.

[59] Ibid. 195-196.

Table 1. Properties of Infrastructure

properties	examples
Embedded Infrastructure is "sunk into and inside of other social structures ... arrangements, and technologies. People do not necessarily distinguish the several coordinated aspects of infrastructure."	Services such as television, internet access, and phone service may be viewed as one amorphous utility even though they may involve the coordination of distinct service providers, hardware and cabling systems, and software protocols.
Transparent It supports tasks invisibly, and does not have to be reproduced or reassembled in order to facilitate action. It is already assembled and functioning. Infrastructures are the unseen substrates of informational and physical spaces.	Infrastructure is often only revealed when it ceases to function properly. The complexity of above and below ground telephone cabling, routing and switching (not to mention the people who build and maintain these systems) may all go unnoticed until someone picks up the receiver and there is no dial tone.
Extended in reach or scope Infrastructure has reach or scope "beyond a single event or one-site practice."	Bathtubs, sinks, and toilets are thought of as separate devices, but they are really inputs and outputs to the larger plumbing system of a residence, and that residence is both an input and output of a larger system of water delivery and waste management.
Learned as part of membership "Strangers and outsiders encounter infrastructure as a target object to be learned about. New participants acquire a naturalized familiarity with its objects as they become members."	Toilet training as an almost universal experience with a human machine interface designed to both facilitate and obfuscate the infrastructure of waste disposal.
Interfacing Infrastructure achieves its aforementioned transparency by interfacing with existing infrastructures and their inherent protocols and standards.	Examples include the design of packaging to comply with palletized and containerized shipping, and standardization of the potato genome to facilitate the large scale production of french fries.
Limited by base upon which its installed	For example, computers are dependent upon the existing electrical system.
Incremental repair Infrastructure is repaired "in increments - not all at once or globally."	If I find that I am unable to check my email, I need to determine if the problem resides in my email client, my computer's wireless connection to my router, my router's connection to my modem, a problem with my email server and its attendant connections to the internet, or any of the numerous exchanges and interconnects in between.

First, infrastructure is *embedded*, “sunk into and inside of other social structures ... arrangements, and technologies. People do not necessarily distinguish the several coordinated aspects of infrastructure.” [60] For example, services such as television, internet access, and phone service, may be viewed as one amorphous utility even though they may involve the coordination of distinct service providers, hardware and cabling systems, and software protocols.

Second, infrastructure is *transparent.* It supports tasks invisibly, and does not have to be reproduced or reassembled in order to facilitate action. It is already assembled and functioning. [61] Edwards concurs with this assessment when he argues that “[M]ature technological systems–cars, roads, municipal water supplies, sewers, telephones, railroads, weather forecasting, buildings, even computers in the majority of their uses–reside in a naturalized background, as ordinary and unremarkable to us as trees, daylight, and dirt.” [62] Infrastructures are the unseen substrates of informational and physical spaces.

Infrastructure is often only revealed when it ceases to function properly. It may only come into focus when it is broken or disrupted. [63] [64] Common examples of this include a lack of cell phone reception (“no bars”), temporary loss of wireless internet connectivity, and brief power outages after electrical storms; all of which reveal extensive and interconnected technical systems that are often taken for granted. For instance, the complexity

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[60] Susan Leigh Star, “The Ethnography of Infrastructure,” *American Behavioral Scientist* 43, no. 3 (1999): 381.

[61] Ibid.

[62] Paul N. Edwards, “Infrastructure and Modernity: Force, Time, and Social Organization in the History of Sociotechnical Systems.” In *Modernity and Technology,* eds. Thomas J. Misa, Philip Brey and Andrew Feenberg (Cambridge: The MIT Press, 2003), 185.

[63] Graham and Thrift. “Out of Order: Understanding Repair and Maintenance,” 9.

[64] Star. “The Ethnography of Infrastructure,” 382.

of above and below ground telephone cabling, routing and switching (not to mention the people who build and maintain these systems) may all go unnoticed until someone picks up the receiver and there is no dial tone.

Third, infrastructure has reach or scope *"beyond a single event or one-site practice."* For example, bathtubs, sinks, and toilets are thought of as separate devices, but they are really inputs and outputs to the larger plumbing system of a residence, and that residence is both an input and output of a larger system of water delivery and waste management. [65]

Fourth, infrastructure is *"learned as a part of membership."* "Strangers and outsiders encounter infrastructure as a target object to be learned about. New participants acquire a naturalized familiarity with its objects as they become members." [66] Edwards takes this idea of membership even further, arguing that "belonging to a given culture means, in part, having fluency in its infrastructures." [67] For example, toilet training, a storied and often contentious subject since the foundation of the discipline of psychology, is often articulated in terms of human cognitive and physical development, but is neglected as an almost universal experience with a human machine interface– an interface designed to both facilitate and obfuscate the infrastructure of waste disposal.

Next, infrastructure achieves its aforementioned transparency by *interfacing* with existing infrastructures and their inherent protocols and standards. [68] Examples include

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[65] Susan Leigh Star, "The Ethnography of Infrastructure," *American Behavioral Scientist* 43, no. 3 (1999): 381.

[66] Ibid.

[67] Paul N. Edwards, "Infrastructure and Modernity: Force, Time, and Social Organization in the History of Sociotechnical Systems," in *Modernity and Technology,* eds. Thomas J. Misa, Philip Brey and Andrew Feenberg (Cambridge: The MIT Press, 2003), 191.

[68] Susan Leigh Star, "The Ethnography of Infrastructure," *American Behavioral Scientist* 43, no. 3 (1999): 381.

the design of packaging to comply with palletized and containerized shipping, and standardization of the potato genome to facilitate the large scale production of french fries.

Infrastructure also inherits the strengths and limitations of the base upon which it is installed. [69] For example, computers are dependent upon the existing electrical system. In addition, early computer networks were built upon existing telephone networks.

Finally, *infrastructure is repaired "in increments* - not all at once or globally." [70] In their article "Out of Order: Understanding Repair and Maintenance," Stephen Graham and Nigel Thrift make the argument that increased connectivity makes it harder to isolate the object of repair. "Is it the thing itself, or the negotiated order that surrounds it?" [71]

If, for example, I find that I am unable to check my email, I need to determine if the problem resides in my email client, my computer's wireless connection to my router, my router's connection to my modem, my email server and its attendant connections to the internet, or any of the numerous exchanges and interconnects in between.

The properties described by Star and detailed above [72] highlight the reach of infrastructure's radical monopoly. It's important to note that these qualities extend that reach across the globe, making it difficult to separate infrastructure's importance from that of the practices and transactions it enables. [73] For example, if there were a problem with a

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[69] Ibid. 382.

[70] Ibid.

[71] Stephen Graham and Nigel Thrift, "Out of Order: Understanding Repair and Maintenance," *Theory, Culture & Society* 24, no. 3 (2007): 4.

[72] Susan Leigh Star, "The Ethnography of Infrastructure," *American Behavioral Scientist* 43, no. 3 (1999): 381.

[73] Susan Leigh Star, "The Ethnography of Infrastructure," *American Behavioral Scientist* 43, no. 3 (1999): 381. Let's acknowledge the regional bias of this text. In many ways, the worthiness of DIY Infrastructure as an object of study is related to its contrast to the 'established' infrastructural systems we rely on in the 'developed' world. Of course, for many of the world's people, ALL infrastructure is DIY. As Edwards states, the "notion of infrastructure as an invisible, smooth-functioning background 'works' only in the developed world.

computer system of an airline, it may be difficult to separate the disruption of the computer system from any resultant disruptions of the transportation of people and freight around the world.

Some of the difficulty in isolating or separating components of infrastructure results from the fact that systems are built on top of others. This distinction between first order (original) and second order (later) systems is discussed by Van Der Vlueten, who argues that "[c]ontrary to the builders of first order systems, second order system builders typically create and control only a minor part of the elements in their systems. Their main task is to coordinate the interlacing of networks built and controlled by others. [...] This includes systems for collection and treatment of industrial and domestic waste, just-in-time production systems in industry, mass tourism, and a worldwide finance and exchange market system.[74]" For example, when interstate shipping, we might discuss the interstate highway system as first order, and the logistics of fleets of trucks as second order.

Because of this difficulty in isolating a distinct subject, infrastructure is a sort of wicked problem in a black box. As discussed by Rittel and Buchanan, wicked problems are messy and indeterminate–or, to use Star's phrase–extended in reach or scope. As with other wicked problems, the boundaries of infrastructure are difficult to isolate, and the effects of a designers' interaction with it may have unanticipated consequences.

[74] Erik Van der Vleuten, "Infrastructures and Societal Change. A View from the Large Technical Systems Field," *Technology Analysis & Strategic Management* 16, no. 3 (2004): 404-405.

The Materiality of Infrastructure

So far we have not made a distinction regarding the materiality of infrastructure. It is important to note that human or social components of infrastructure are just as important as physical components. As many scholars of infrastructure have demonstrated, its definition also needs to include its social components. For example, Lee, Dourish and Mark define infrastructure as "an underlying framework that enables a group, organization, or society to function in certain ways."

Its also important to consider that since infrastructure requires interoperable technologies and attendant behaviors, that standards are necessary. Busch divides standards into four categories: Olympic, in which there is only one "best" choice or match for a set of criteria at any given time or place; Filters, which separate things which meet or exceed criteria from those that do not; Ranks, which create hierarchies in relationship to the degree to which things being evaluated meet criteria; and divisions, which are different categories without hierarchical rankings[75].

Furthermore, Susan Leigh Star's properties described above detail characteristics of infrastructure which are common to both physical and informational systems. As I discuss in the next section, distinctions between physical and informational systems are increasingly hard to make because most systems involve both material and informational components. Informational systems have physical substrates, and physical systems may have informational components. The term "soft infrastructure" is used to refer to services such as the banking system or airline ticketing system. Because large physical infrastruc-

[75] Lawrence Busch, *Standards: Recipes for Reality* (Cambridge: The MIT Press, 2011), 42-47.

tures such as sewage systems or railroad networks may be the first things that come to mind when infrastructure is discussed, it is important to note that this distinction is sometimes made. The criticality of infrastructure–something I discuss in the next section–can be a concern for soft and hard infrastructure alike.

Critical Infrastructure and Its Protection

According to Egan, a scholar who has written extensively on critical infrastructure and crisis management, “The term ‘critical infrastructure’ is used widely in the governmental, management and academic literatures, but it has largely been defined by illustration and categorization rather than by a set of characteristics that can be isolated for analysis and prediction.” [76] To resolve this ambiguity, he suggests the following attributes of critical infrastructure: the use of operational pathways necessary for routine function; a lack of easy substitutes; the potential to cause real harm when disrupted; and (in agreement with Star) being embedded within integrated systems. [77] He notes, however, that definitions of critical infrastructure are expanding as globalization and technological advances add new critical elements and “nodes of criticality,” and because the study of infrastructural systems is revealing existing critical points which had gone unnoticed. [78]

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[76] Matthew Jude Egan, “Anticipating Future Vulnerability: Defining Characteristics of Increasingly Critical Infrastructure-like Systems,” *Journal of Contingencies and Crisis Management* 15, no. 1 (2007): 4-17.

[77] Ibid.

[78] Ibid.

It is the potential for harm which truly separates these attributes from those advanced by Star and discussed in the first chapter of this document. While Star offers a set of characteristics that define all infrastructure, from massive intercontinental railways to the systems that small offices use in their day-to-day operations, Egan is attempting to limit discussion to cases of loss of life, limb, and livelihood. Of course, the degree to which infrastructure is interconnected can muddle this distinction. At first thought, telecommunications may seem less than critical–would I, for example, freeze to death or suffer from dehydration without a smart phone? While my smart phone may not keep me from suffering these fates by itself, we know that our ability to communicate with others–to seek and receive aid–is mediated by telecommunication which, in turn, is reliant on infrastructure. Broadly, telecommunication is the medium through which other infrastructures are managed, and, as I shall discuss, digital infrastructure causes different infrastructure to become even more tightly coupled. Information and communication technologies and digital media, increasingly ubiquitous, are not only subject to failure because of their dependence upon the electrical system, but may enable, encourage, or amplify both the social and physical effects of its (and their own) disruption. So, in a crisis event in which an infrastructural system is disrupted, some citizen responses may result in undue strain on other infrastructural systems and trigger secondary disruptions.

But what about DIY infrastructure? Where does it fit into this discussion? First, the DIY infrastructure projects discussed in this document are non-critical simply because they do not have a large base of users or dependents. That does not mean that they could not become critical if that user base increased. DIY infrastructure is more significant to this discussion because it can address the problem (or complicate the picture) of criticality. In fact, one key attribute of some of the projects I am about to discuss is that they have been designed with redundancy in mind. Redundancy can ameliorate problems of criticality by providing systems with a second way of operating when the first is unavailable. These projects are new entrants into a complicated space of undetermined responsibilities: who or what should be responsible for protecting against and/or repairing disruptions to critical infrastructure? In the next section, I frame this as a conflict between institutional responsibilities and market forces.

Many DIY infrastructure projects operate in a void between the interests of infrastructures' owners and operators and its users, and that void may be revealed by infrastructural disruptions. While much infrastructure is privately owned and managed, the motivations of its stakeholders and of the users of infrastructure may not always perfectly align. James Lewis, director of the Technology and Public Policy Program at the Center for Strategic and International Studies, raises the point that cyber security can be considered a public good and is therefore subject to market failure. "Markets are inefficient at supplying goods and services in situations where groups of people must work together to achieve a good outcome but the incentive for investment and cooperation is low. In these situations, the private sector will not produce an optimal outcome." [79] While Lewis was writing specifically on security from cyber attacks, we can extend his characterization of market inefficiency to disruptions of infrastructure from other causes.

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[79] James Andrew Lewis, "Aux armes, citoyens: Cybersecurity and regulation in the United States" *Telecommunications Policy* 29, no. 11 (2005): 821–830.

According to Egan, "In the United States, markets alone will usually only support investment in safety up to the limits of liability established by the Hand Rule which states that: liability pertains where the cost of precaution (B) is less than the cost of an accident (L) times its probability (P) or where $B<PL$." This may mean that things like redundant safety systems are deemed unnecessary and are not seen as profitable. [80] So, during a blackout, cellular service may be interrupted after battery backups have been spent, because cellular phone towers, which typically have a backup battery life of about four hours, may not be fitted with redundant backup batteries or emergency generators.[81]

So, the interests of the public – broadly, those of us who rely on critical infrastructures but who do not profit from direct investment in them – may not be the same as the interests of its owners. Though not truly in control of privately owned technical systems, government may attempt to address this by providing oversight through measures such as public-private partnerships. However, following a large scale disruption, government may also end up taking the blame, and taxpayers may end up footing the bill: "Complex market dynamics often make the taxpayers bear the burden of providing the CI [critical infrastructure] safety net for private companies, even when they have made choices that decrease systemic reliability. [82]" Regulation encouraging owners of private infrastructural systems to do more to ensure resilience may protect governments from having to step in to clean up in a worst case scenario.

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[80] Matthew Jude Egan, "Anticipating Future Vulnerability: Defining Characteristics of Increasingly Critical Infrastructure-like Systems," *Journal of Contingencies and Crisis Management* 15, no. 1 (2007): 4-17.

[81] Stephen H. Conrad, Rene J. LeClaire, Gerard P. O'Reilly, and Huseyin Uzunalioglu, "Critical National Infrastructure Reliability Modeling and Analysis," *Bell Labs Technical Journal* 11, no. 3 (2006): 57–71.

[82] Matthew Jude Egan, "Anticipating Future Vulnerability: Defining Characteristics of Increasingly Critical Infrastructure-like Systems," *Journal of Contingencies and Crisis Management* 15, no. 1 (2007): 4-17.

In addition, De Bruijne and van Eeten propose that “[w]ithout governmental intervention, CIP [critical infrastructure protection] - efforts in privatized industries will not take into account the full social costs and benefits of security,” but warn us that when “[f]aced with threats of large-scale CI disruptions, governments will be more or less pushed to become the lender of last resort. [83]” This raises the specter of expensive and unpopular government bailouts compounding the problems of infrastructural disruptions caused by disaster or terrorism. Critical telecommunication infrastructures are a public good and the interests that maintain them will not always do so in a way that ensures their resilience to disruption. Not only is this at odds with the interest of the public, it is at odds with the interests of government, which may be inappropriately blamed for these vulnerabilities while being asked to intercede – at considerable expense – to repair or maintain these infrastructures.

DIY infrastructure is a new type of response to this conflict. It can be an attempt to address disruptions of critical infrastructure and affect debate about responsibility and blame during and after those disruptions. For example, the design of the Cloacina, a DIY sanitation infrastructure project discussed in a later chapter, is sometimes framed in terms of crisis response. One recent Cloacina publication, *A Sewer Catastrophe Companion: Dry Toilets for Wet Disasters* [84], is a how-to guide to sanitation during a large scale disruption of the sewer system. DIY infrastructure projects are often informed by the possi-

[83] Mark de Bruijne and Michel van Eeten, “Systems that Should Have Failed: Critical Infrastructure Protection in an Institutionally Fragmented Environment,” *Journal of Contingencies and Crisis Management* 15, no. 1 (2007): 18-29.

[84] Molly Danielsson and Mathew Lippincott, “A Sewer Catastrophe Companion: Dry Toilets for Wet Disasters,” *Cloacina Development Blog*, October 15, 2012 (1:25 p.m.), http://www.cloacina.org/files/a-sewer-catastrophe-companionsm.pdf.

bility of disruption and by a critique of the reciprocal influence of infrastructure and market forces. The properties of digital media are another, often ignored, factor in these interrelationships.

Digital Media and Infrastructure

Because digital media objects and systems are built upon existing infrastructure, Star and Bowker argue that an understanding of infrastructure is key to the design of digital media software applications. [85] As new infrastructures are built upon old ones, computational media continue to become imbricated with other technical systems. New digital media systems, which may already be difficult to distinguish from the conduits of their creation and distribution, erode the conceptual separation of infrastructure and computing.

For instance, software running on a server and communicating with a web browser on a client computer is not only dependent on the obvious hardware and software, including the client and server computers, routers, TCP/IP, DNS and other protocols, but also on an elaborate system of undersea cables and on the electrical system, which is, in turn, dependent on systems for extracting and transporting fossil fuels. The technologies that constitute the electrical system are, in turn, dependent on systems for extracting and transporting fossil fuels. Looking at another set of relationships between the same subjects, systems for extracting and moving oil and gas may be dependent on the electrical

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[85] Susan Leigh Star and Geoffrey C. Bowker, "How to Infrastructure," in *The Handbook of New Media: Social shaping and social consequences of ICTs*, eds. Leah A. Lievrouw and Sonia Livingstone (London, UK: SAGE Publications, 2002), 151-162. p230

system–to provide light, for example–and on the internet– which is used in a number of ways to facilitate their sale and transportation. These technologies are interdependent.

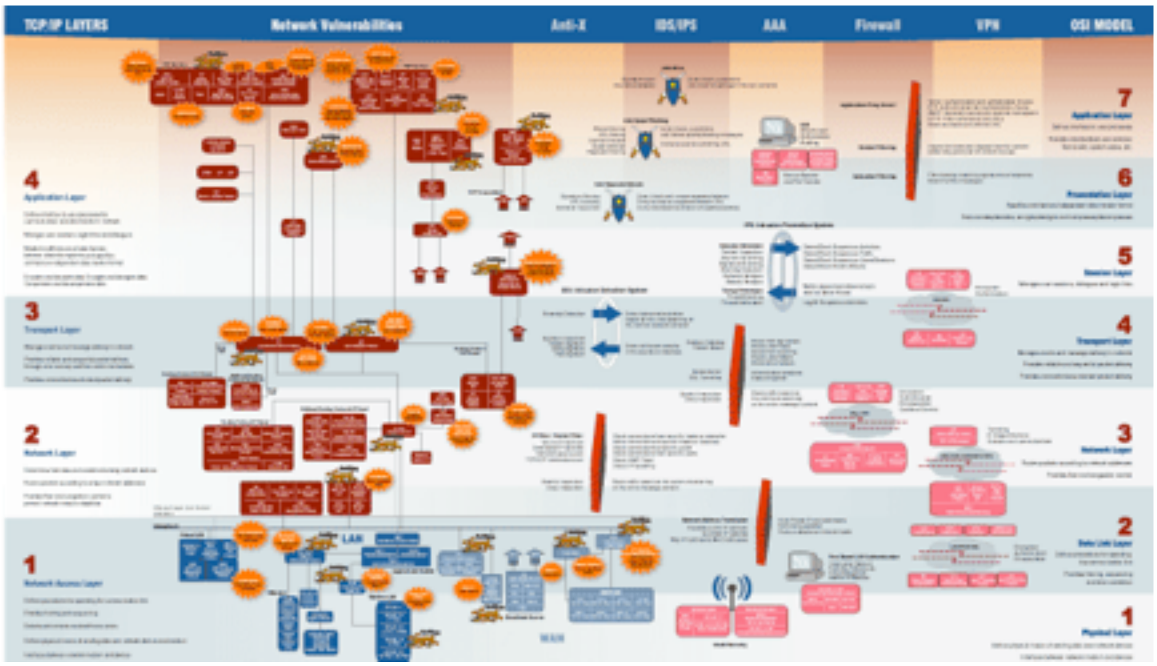

Figure 5. Map of network security vulnerabilities (http://media.sharewareconnection.com/images/large/network-security-map-poster-32076.gif, accessed Sept. 25, 2012.)

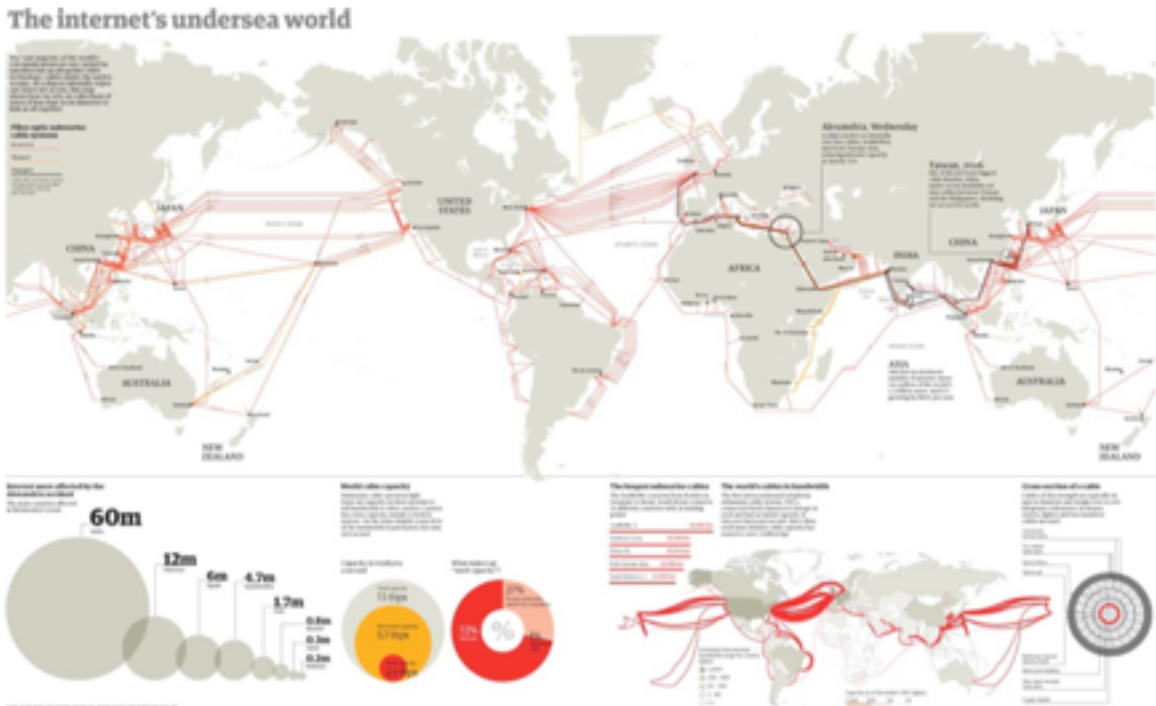

Figure 6. Part of the physical infrastructure of the internet (http://thumbnails.visually.netdna-cdn.com/the-internets-undersea-world_50290b4c451c6.jpg, accessed Sept. 25, 2012.)

Writing on the necessity of electrical infrastructure to the digital, Brian Carroll, a scholar of architecture, argued that “It is only an illusion that a ‘virtual’ building on a computer screen can be totally detached from the ‘actual’ world of architectural objects and their physics. The computer tool is housed by an electrical building connected to the electrical power system. Together this infrastructure materially represents and sustains the trompe l’œil of other-worldly immateriality while simultaneously depending upon a physical assemblage of wires, plugs and sockets to distribution lines and poles, transformers, transmission towers and electrical power plants. Without these extensions, Cyberspace would cease to exist."[86] Greg Downey shares this awareness of the physical substrates of the internet, but also echoes Manovich's arguments regarding the modularity of digital media: "the key process tying its component net- works together is digital convergence: the ability of nearly any kind of information—text or graphics, audio or video, even complex three-dimensional environments—to be sampled, translated, and compressed into a common mathematical language of ones and zeros.[87]" So, the virtual space that we perceive as existing between devices–a space we may become immersed in to such a degree that we forget the real space which creates it–depends on the continued functioning of forgotten or ignored physical artifacts. It also depends on standards and protocols which establish the shared parameters to secure its interoperability. As Edwards describes it "The basis for this massive interconnectivity is a set of protocols, or software and hardware standards, developed over three decades by an anarchical but surprisingly effective community of hackers and computer professionals.[88]" This inversion of the infrastructure of the internet is intended to facilitate our discussion of the ties between digital media and infrastructure.

Digital Media as Infrastructure

Software also functions as infrastructure. Consider the bots used by search engines to index websites or by banks to facilitate financial transactions. We can also consider the

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[86] Brian Caroll, "Seeing Cyberspace: The Electrical Infrastructure as Architecture," *Sarai Reader: Cities and Everyday Life*, no. 02 (2002): 250, http://www.sarai.net/publications/readers/02-the-cities-of-everyday-life/04cyber_electric.pdf.

[87] Greg Downey, "Virtual Webs, Physical Technologies, and Hidden Workers: The Spaces of Labor in Information Internetworks," *Technology and Culture* 42, no. 2 (2001): 212.

[88] Paul N. Edwards, "Y2K: Millennial Reflections on Computers as Infrastructure," *History and Technology* 15, nos. 1-2 (1998): 12.

web browser, which highlights an increased difficulty in determining the scale of infrastructure. Volkmar Pipek and Volker Wulf, German scholars of ICT-based infrastructure, explains, “[f]or some IT applications, it is often not quite clear whether they will be used as part of a large or a small infrastructure. An Internet browser may usually be employed to browse the global web, but it can also be used very locally, when browsing HTML documents located on the computer's own hard drive. [89]” To which he adds “the concept of infrastructure remains useful regardless of the artifact’s sheer size. [90]” What infrastructure *is* is in many ways determined by the situation. Pipek and Wulf provide the example of railway networks: while they may span entire continents, that scale is not significant to a commuter who takes the train for a few miles to and from work. [91] Digital media–such as the web browser we just discussed–highlight this difficulty in determining scale, but they also complicate it because they are capable of functioning in different states depending on their ability to network with other computers and software.

As Pipek and Wulf suggest, the web browser has become another layer of infrastructure as applications which once ran on a local computer–the computer of the “user” or interactor–are increasingly moved to “the cloud,” running on remote computers and being accessed through the interactor’s web browser. For example, if someone’s browser fails to operate they may be unable to access addresses, phone numbers or schedules which they have stored in a web application such as Google Calendar. The browser has become an interface to offline transactions–appointments, shipments, payments for physical labor.

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[89] Volkmar Pipek and Volker Wulf, “Infrastructuring: Toward an Integrated Perspective on the Design and Use of Information Technology,” *Journal of the Association of Information Systems* 10, no. 5 (2009): 456.

[90] Ibid.

[91] Ibid.

There are less mundane examples of an eroding boundary between offline and online. For instance, I can control remote cameras or robots through a web browser, a practice dating back to Goldberg and Santarromana's Telegarden installation at the Ars Electronica festival in 1996 and 1997. Since then, the number of physical, or "real-world" interactions that are mediated through internet reliant software applications has grown significantly. For example, consumer grade remotely piloted aircraft such as the Parrot AR Drone Quadricopter, available for less than $300 US, are capable not just of being piloted, but of recording and streaming HD video over local wireless internet.

Information and Communication Technologies as Infrastructure

Of course, this "information infrastructure" is determined not just by its physical components or hardware, but also by the properties of digital media discussed earlier. For example, Murray's observation that the computer is an encyclopedic medium informs a discussion of enterprise resource planning software such as SAP or PeopleSoft as much as it does a discussion of digital narrative. These software systems combine information from a variety of activities including accounting, manufacturing, shipping, sales, and service, creating consistent and integrated information management for businesses. They underpin a wide variety of transactions that customers have with businesses of various sizes and are an example of a digital media system of significant import to everyday life in many parts of the world, but have been largely ignored by digital media scholars.

One of the more significant attributes arising from the combination of digital media and infrastructure is reflexivity. Pipek and Wulf call upon Castells to describe this property. “In an ICT-based infrastructure, an additional reflexive level is possible that traditional infrastructures could not provide. As Castells has repeatedly shown, information systems can form reflexive infrastructures, in the sense of tools that can mediate their own further development. The very ubiquity of information and communication allows e-infrastructures to provide representations of their inner workings as well as tools for discussing, negotiating and modifying them. [...] As the space for these tools and representations opens up, traditional competence/skill profiles and professionalization structures become more permeable. These both allow and require new methodological considerations (for example, with regard to different divisions of work between professional designers and users).”[92] In employing the affordances of digital media–notably, the encyclopedic and procedural–ICT-based infrastructures create new possibilities for the own modification. Many, if not all of the DIY infrastructure projects discussed in this document would not be possible without this property of reflexivity.

Infrastructure as an Input into a Digital Media System

One example of this reflexivity is traditional infrastructures collecting data that is input into digital media systems. For example, Google Maps can display current traffic conditions on major roads, and the websites of shipping services such as UPS or FedEx are dynamically generated to respond to tracking inquiries and report the current location of packages en route. In both of these examples, data from the physical world–the location of objects such as packages or automobiles–is displayed in a way that may alter in-

[92] Ibid. 454.

frastructure use and provide real-time feedback on its operations. Drivers may choose different routes or times to travel, and urban planners may assess larger interactions within a transportation system.

For an example less conspicuous to North America's drivers and consumers, but no less significant to their way of life, see the website of an independent system operator (or ISO). An independent system operator is a regulatory body established by the United States Federal Energy Regulatory Commission to monitor the electrical system of a particular geographic region. MISO is an independent system operator for the midwestern U.S., and its website displays the current demand and load of a subsection of the North American electrical grid.

Figure 7. Load graph from Midwest independent service operator (http://www.midwestmarket.org/page/Real+Time+Info+%28EOR%29 accessed March, 28, 2011)

While graphically mundane and informationally obtuse, this represents something rather profound: Because the affordances of digital media allow the load and demand of segments of the electrical grid to be recorded, displayed and accessed in a speed close to real-time, energy has become a commodity subject to financial speculation. To be clear, we aren't talking about barrels of oil, or about tons of coal. We are talking about the electricity itself. Of course, speculation affects pricing, and pricing affects everything from the cost of running a server farm to the cost of filling up a car with gasoline. Proponents of this practice claim that it keeps costs low. Opponents claim that the system has been abused and resulted in black outs. Energy could not have become such a commodity without the affordances of digital media.

To understand the confluence of digital media with infrastructure and with DIY practice, we need to look at each of them in turn. Let's start with the properties of digital media, which may be more familiar.

Manovich describes a new media object as having the following properties: numerical representation, modularity, automation, variability, and transcoding [93]. While all of these are significant to digital media in general, their significance in informing the capacities of infrastructure requires further attention. Numerical representation refers to the fact that since new media objects are digital artifacts, they can be described mathematically and are thus computable. Manovich explains it this way: "[f]or instance, by applying appropriate algorithms, we can automatically remove "noise" from a photograph [...] in short, media becomes programmable. [94]"

Modularity refers to the fact that the components of a digital media object "continue to maintain their separate identities. [95]" For example, a jpeg in a web page is something that I can move or remove without necessarily destroying other components of the page as might be the case with its paper analog.

The principle of automation descends from the first two principles and describes the ability of computers to perform operations on numerically represented components

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[93] Lev Manovich, *The Language of New Media* (Cambridge: The MIT Press, 2002), 27-48.

[94] Ibid. 27.

[95] Ibid. 30.

through procedures.[96] One example of this is Smart Pigs, a system deploying sensor equipped robots in sewers to "locate corrosion or any other anomalies in pipelines [...], implement a repair or replacement program, and evaluate the effectiveness of a corrosion inhibitor program[97]."

Figure 8. Smart Pigs robot (http://www.gasco.com.eg/images/pig.gif, accessed Sept. 25, 2012.)

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[96] Ibid. 36.

[97] William O'Brien and Lucio Soibelman, "Technology and Engineering Dimensions: Collecting and Interpreting New Information for Civil and Environmental Infrastructure Management," in *Digital Infrastructures: Enabling Civil and Environmental Systems Through Information Technology,* eds. Thomas Horan and Rae Zimmerman (New York: Routledge, 2004), 23.

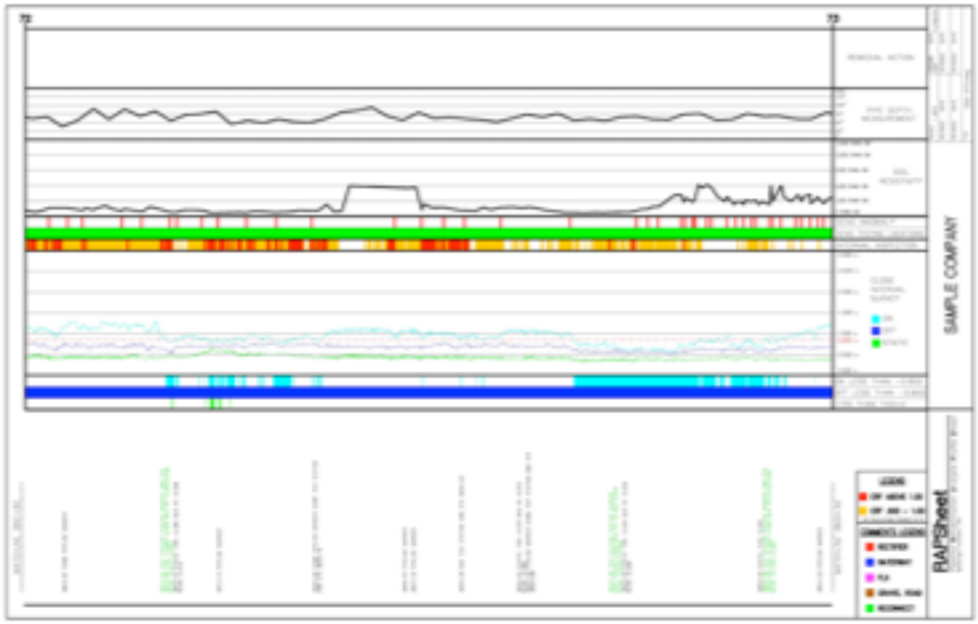

Figure 9. Screenshot of Smart Pigs interface (http://www.mears.net/files/4712/7775/2989/Engineering---Smart-Pig-Data-Evaluation---ILI-Rapsheet_large.gif, accessed Sept. 25, 2012.)

By performing operations (analysis) on numerically represented components (data collected by robots), the system is able to suggest sites of necessary repair. While sewer pipes are not typically considered media objects, we can take the principles that Manovich puts forward as being significant beyond the scope of media, and suggestive of attributes shared by all computer augmented systems.

The principle of variability suggests that a new media object can exist in multiple versions. [98] For example, the MISO website discussed above will yield different results at different times as those times are correlated with specific collections of data.

[98] Lev Manovich, *The Language of New Media* (Cambridge: The MIT Press, 2002), 36.

Finally, Manovich argues that "[b]ecause new media is created on computers, distributed via computers, and stored and archived on computers, the logic of a computer can be expected to significantly influence the traditional cultural logic of media. [99]" One of the key questions posed by DIY infrastructure is the reach or scope of the influence of this logic. In what ways will the affordances of the computer change the capacities of the infrastructures supporting contemporary life, and how will those capacities change our agency?

Murray describes the computer as a medium that is encyclopedic, procedural, spatial and participatory [100]. Its encyclopedic nature includes the "density of a quantitative database […] like stock market quotations [101]." In terms of infrastructure, the examples of dynamically generated websites displaying traffic, shipping and electrical system information mentioned above rely on this property.

Most examples of infrastructure discussed within this document involve the movement of information and materials through space. Roads, electrical wires, and air traffic control systems are all examples of this. The spatial nature of digital media complements the spatial nature of these infrastructures, enabling navigable simulations and other ways of representing their complexities. While maps may be suited to roads, which are–for the most part–locked to the surface of the earth and more likely to intersect than overlap, something like the system of pipes or wires running beneath a city is more difficult to

[99] Ibid. 46.

[100] Janet H. Murray, *Inventing the Medium: Principles of Interaction Design as a Cultural Practice* (Cambridge: The MIT Press, 2011), 56.

[101] Ibid. 110.

represent in two dimensions. Pipes may pass above or below each other, leaving the invisible expanse of the underworld for the hidden vertical nooks of buildings.

In the case of the computer as a procedural medium, take the example of the acoustic monitoring, in which software is designed to predict structural failures in bridges [102]. Predictions of structural failure result from procedures which analyze recorded acoustic data and identify anomalies. Without the procedural affordance of the computer, the system would only be able to record and display acoustic events–it would not be able to assess and act on the information it collected.

Finally, and most importantly, we come to the computer as a participatory medium. As was the case with Manovich's discussion of the cultural logic of the computer, and my questions regarding the extent of its reach, DIY infrastructures investigate the limits of the computer as a participatory medium. Specifically, they raise questions about the inheritance of the participatory affordance by descendent systems: if digital media is combined with infrastructure does infrastructure become participatory?

Gateways and Infrastructure APIs

Architectural theorist Kazys Varnelis seems to think so. In an essay called "Systems Gone Wild: Infrastructure After Modernity, [103]" he argues for the creation of infrastructure APIs. An API, or application programmer interface, is a phrase borrowed from object

[102] William O'Brien and Lucio Soibelman, "Technology and Engineering Dimensions: Collecting and Interpreting New Information for Civil and Environmental Infrastructure Management," in *Digital Infrastructures: Enabling Civil and Environmental Systems Through Information Technology,* eds. Thomas Horan and Rae Zimmerman (New York: Routledge, 2004), 22.

[103] Kazys Varnelis, "Systems Gone Wild: Infrastructure After Modernity," *C-Lab*, accessed November 3, 2011, http://www.c-lab.columbia.edu/0162.html.

oriented programming specifying different allowable objects, classifications and structures. These infrastructure APIs would make more relevant government data available to software developers in an attempt to improve the efficiency of infrastructure. For example, Varnelis argues that "instead of suggesting that we add lanes to highways, the government might find a lower-cost solution in simply making more sensor data publicly available to citizens […] This sort of thinking could be applied to electric power as well […] Large commercial customers such as factories and oil refineries already know when electric power is more expensive and have the ability to plan around that." The MISO graph discussed above is an example of such a system. Varnelis continues"[w]hy shouldn't customers be encouraged to respond to power fluctuations dynamically? Coming up with new forms of 'human hacking' or social engineering is a key to rethinking infrastructure." [104] These new forms of human hacking are precisely what this document details.

These APIs that Varnelis is suggesting are examples of gateways. A gateway is something that allows new systems to be joined with existing ones, allowing them to interoperate.[105] Software gateways are common in information infrastructure, permitting "multiple systems to be used as if they were a single integrated system, though rough patches often remain that must be smoothed over by user action.[106]" XML is an example of a software gateway, as it allows things like data and presentation to be separated. Ac-

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[104] Ibid.

[105] Paul N. Edwards, Steven J. Jackson, Geoffrey C. Bowker, and Cory P. Knobel, "Understanding Infrastructure: Dynamics, Tensions, and Design," *Report of a Workshop on History & Theory of Cyberinfrastructures* (University of Michigan, School of Information, 2007), 16.

[106] Paul N. Edwards, Geoffrey C. Bowker, Steven J. Jackson, and Robin Williams, "Introduction: an agenda for infrastructure studies," *Journal of the Association for Information Systems* 10, no. 5 (2009): 367.

cording to Egyedi "XML creates flexibility at different levels. For example, firstly, the structure of XML documents is defined independently from the way they are processed. Because of this, the same data in XML documents can be understood, for example, by XML-compliant printing, browsing, database and text processing tools. Thus, XML is a gateway between, on the one hand, documents and data, and, on the other hand, processing tools.[107]" Egyedi also raises the example of the ISO shipping container, which functions as a gateway between different modes of transportation[108].

Digital Infrastructures

Situations in which software as infrastructure controls physical infrastructural systems may portend dire consequences. This issue is commonly raised in exaggerated discussions of cyberwar, in which, for example, physical systems are brought down by interfering with the software systems that manage them. The Stuxnet virus, a worm which incubates in Windows computers, is an example of this.

Stuxnet [109] is spread through USB "thumb" drives, which has allowed it to attack computers that are not connected to the internet. It uses infected Windows computers to attack a particular type of embedded microcontroller made by the Siemens Corporation. The virus is suspected to have been developed to disable Iran's production reactors. According to a brief by the computer security firm F-secure, "In theory […] it could adjust

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[107] Tineke Egyedi, "Infrastructure Flexibility Created by Standardized Gateways: The Cases of XML and the ISO Container," *Knowledge, Technology & Policy* 14, no. 3 (2001): 46.

[108] Ibid.

[109] Bruce Schneier, "Stuxnet," *Schneier on Security Blog*, last modified October 7, 2010, accessed April 4, 2011, http://www.schneier.com/blog/archives/2010/10/stuxnet.html.

motors, conveyor belts, pumps. It could stop a factory. With right modifications, it could cause things to explode[110]." The Stuxnet worm is an example of a SCADA vulnerability. SCADA, or supervisory control and data acquisition systems, are software systems facilitating the management of industrial facilities such as factories, water treatment plants, and oil refineries.[111]

These discussions of digital media as infrastructure are complicated by the increasing invisibility of their subject: As technologies become ubiquitous it becomes more difficult for us to differentiate them from the messages they carry and the processes that they enable. How soon will the phrase "online banking" seem redundant? Just as plumbing and electricity altered human habitation to the extent that they are in some ways indistinguishable from it, information and communication technologies are becoming indistinguishable from a new infrastructure born of the globalization they catalyzed.

The introduction of digital media to infrastructure also gives infrastructure new capabilities. These capabilities are discussed at length by Massoud Amin, a professor of engineering at the University of Minnesota. He provides several examples of uses of digital infrastructure within the electrical system–either currently employed or in development–including: "using a precise timing signal derived from the GPS to time-tag measurements of AC signals," "transmitting SCADA systems data (usually via telephone circuits)," "enhancing situational awareness by generating real-time pictures of system states and real-time power flow as well as real-time estimation of the systems' state and

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[110] Mikko, "Stuxnet Questions and Answers," *News From The Lab* (blog), last modified October 1, 2010, accessed April 4, 2011, http://www.f-secure.com/weblog/archives/00002040.html.

[111] Kim Zetter, "Attack Code for SCADA Vulnerabilities Released Online," *Wired*, last modified March 22, 2011 (7:09 p.m.), accessed April 1, 2011, http://www.wired.com/threatlevel/2011/03/scada-vulnerabilities/.

topology," and "using data from Low Earth Orbit (LEO) satellites for faster-response control."[112] Most interestingly, the use of digital technologies in electrical power generation and distribution may make possible an increase in the use of DER, or distributed energy resources. Distributed energy resources include "micro turbines, fuel cells, photovoltaics, and energy storage devices,[113]" and an increase in their use would mean a more robust and resilient energy system.

Along with those new capabilities come new problems, among them security concerns about electrical facilities' systems being accessed remotely by hackers, or remote monitoring of electrical facilities meaning that "reduced personnel at remote sites makes them more vulnerable to hostile threats."[114] In addition, and as mentioned briefly above in the discussion of ISO information, Amin argues that the "use of networked electronic systems for metering, scheduling, trading or e-commerce imposes numerous financial risks."[115]

Of course, the affordances of digital media do not overwrite the capacities and constraints of historically entrenched infrastructures; they augment capacities and alter the space of those constraints. For example, digital media is being added to existing infrastructure for repair, maintenance and assessment. In "Technology and Engineering Dimensions: Collecting and Interpreting New Information for Civil and Environmental Infrastructure Management," William O'Brien and Lucio Soibelman describe technologies

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[112] Massoud Amin, "Electricity," in *Digital Infrastructures: Enabling Civil and Environmental Systems Through Information Technology,* ed. Thomas Horan and Rae Zimmerman (New York: Routledge, 2004), 121.

[113] Ibid. 124.

[114] Ibid.

[115] Ibid.

in development which may be deployed to augment existing infrastructure, allowing it to interface with digital media. One example is the Smart Pigs System discussed earlier. Another is "Continuous Acoustic Monitoring for Structures," which record and analyze the acoustic energy "released when, for example, a wire breaks. [116]" This data can then be recorded and analyzed to predict "the time and location of probable wire breaks […] the ability to calculate the frequency of wire breaks allows statistical prediction of future failure rates as well as an assessment of the extent of past failures. Statistical prediction also allows accurate budgeting for future repairs."

[116] William O'Brien and Lucio Soibelman, "Technology and Engineering Dimensions: Collecting and Interpreting New Information for Civil and Environmental Infrastructure Management," in *Digital Infrastructures: Enabling Civil and Environmental Systems Through Information Technology,* eds. Thomas Horan and Rae Zimmerman (New York: Routledge, 2004), 22.

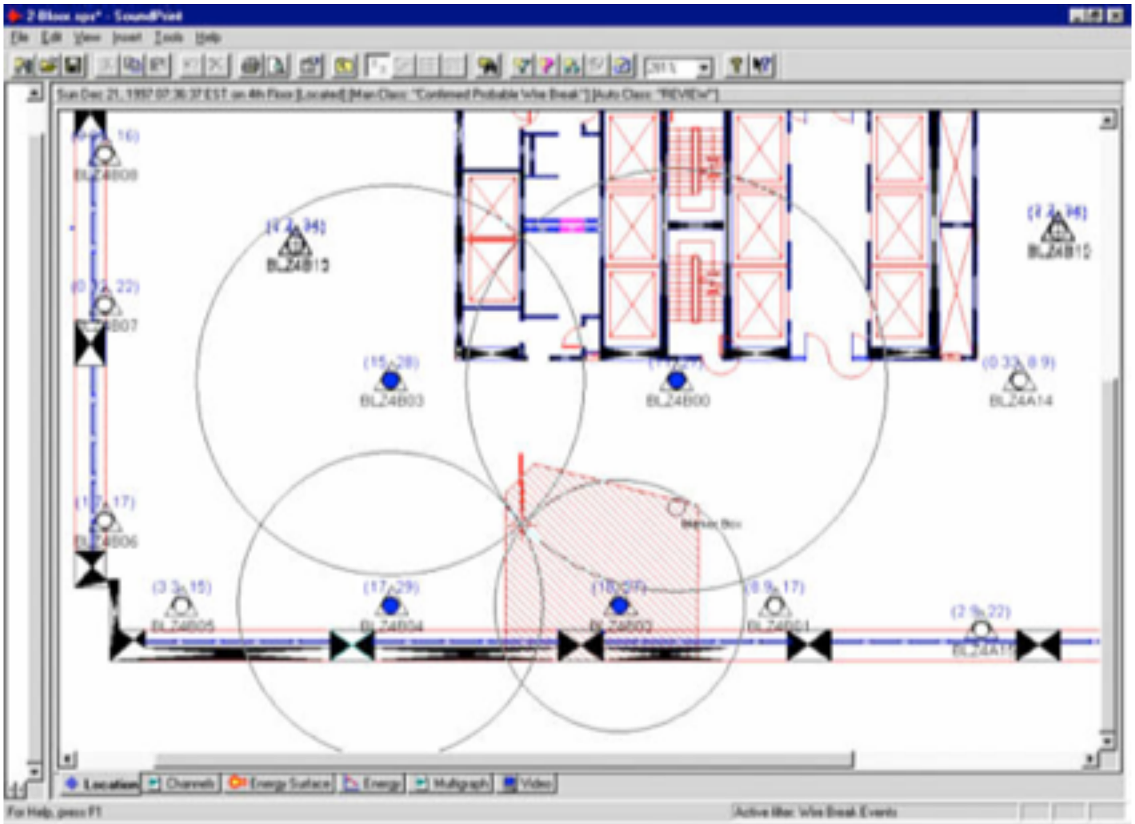

Figure 10. Screenshot of CAMS monitoring software

(http://www.ndt.net/article/wcndt00/papers/idn777/fig7.jpg, accessed Sept. 25, 2012.)

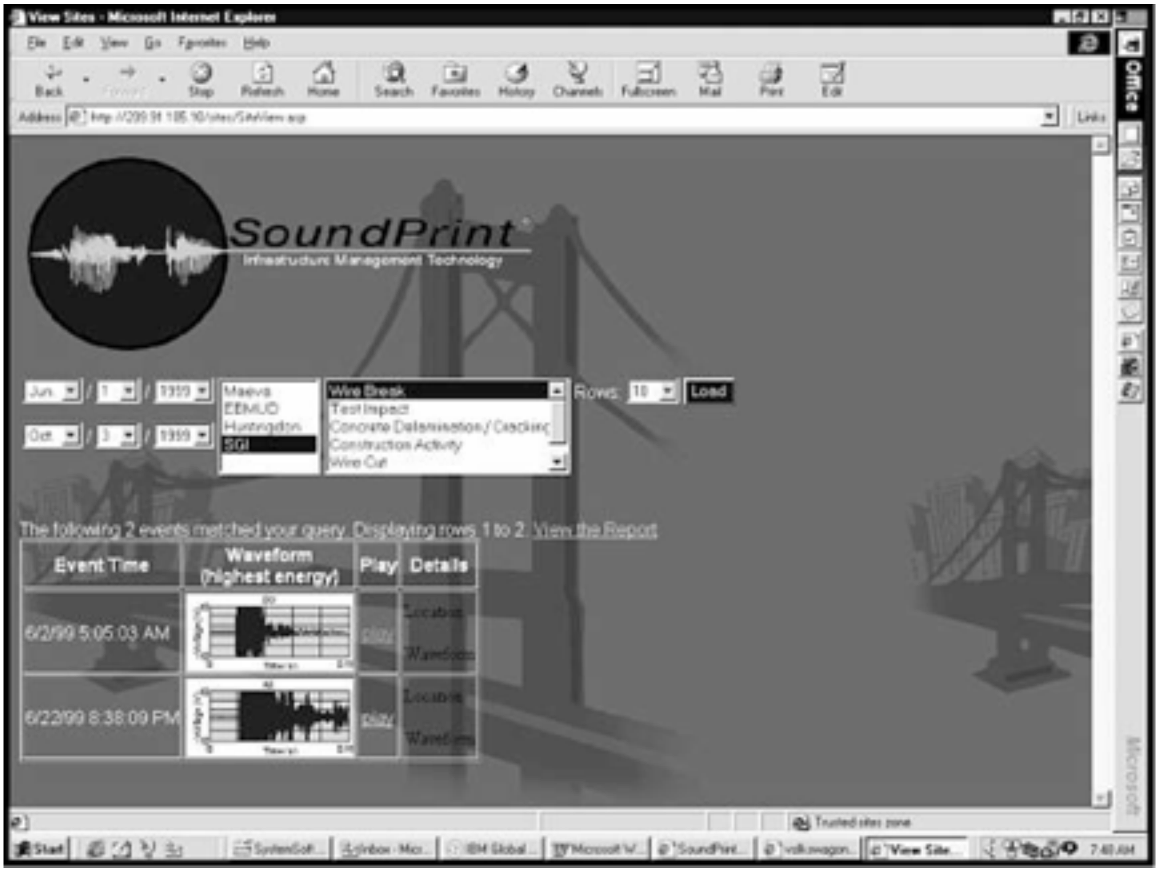

Figure 11. Screenshot of CAMS monitoring software

(http://www.ndt.net/article/wcndt00/papers/idn777/fig13.jpg, accessed Sept. 25, 2012.)

In these examples we can see the application of principles of new media, including numerical representation, modularity, automation, variability, and transcoding [117]; and the affordances of the computer as an encyclopedic, spatial, procedural, and participatory medium [118]. For instance, with "Continuous Acoustic Monitoring for Structures," it is the numerical representation of descendent modularity of digitally recorded acoustic data

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[117] Lev Manovich, *The Language of New Media* (Cambridge: The MIT Press, 2002), 27.

[118] Janet Murray, *Inventing the Medium* (Cambridge: The MIT Press, 2011), 56.

which enables its being transcoded and displayed as a waveform. It is the affordances of the computer as an encyclopedic and procedural medium which allows acoustic data to be recorded and analyzed in such a way that future breakage may be predicted.

These examples, Smart Pigs and Continuous Acoustic Monitoring for Structures, show us what civil engineering and urban planning literature terms digital infrastructure. Just as the phrase digital media is sometimes used to differentiate cultural artifacts which are dependent on the affordances of computers from those that are not, digital infrastructure is a phrase used to identify infrastructures–often traditional "hard" infrastructures such as water and electricity–which are dependent on the affordances of computers. For example, in *Digital Infrastructures: Enabling civil and environmental systems through information technology*, Rae Zimmerman and Thomas Horan argue that "our cities and towns are now fundamentally dependent on technology to provide a range of monitoring, diagnostic, and control information that allows our society to function smoothly with little or no interruption and under a wide range of conditions. Users increasingly have enhanced options to interact with infrastructure, as a result of the expanded infrastructure capabilities IT can provide."[119] But while Zimmerman and Horan believe that this has extended the scope and performance of infrastructure, they also believe that it has increased its interconnectedness.

Interconnectedness creates a number of challenges for designers and policy makers. Some of these are raised by Roy Sparrow, of the Institute for Civil Infrastructure Systems, and Thomas Horan, an E-health researcher: "regulatory shifts toward greater priva-

[119] Rae Zimmerman and Thomas Horan, "What are Digital Infrastructures?" in *Digital Infrastructures: Enabling Civil and Environmental Systems Through Information Technology,* ed. Thomas Horan and Rae Zimmerman (New York: Routledge, 2004): 3.

tization and deregulation, changes in the financing of both capital investment and operations toward increased state-local governmental and private sources," a "shift from an emphasis on new infrastructure toward rebuilding and upgrading existing infrastructure, growing performance expectations by users and customers," a "growing awareness of the interdependence of infrastructure systems with each other and with the natural and built environments," and "transformative change in the means by which technology is integrated into systems design and deployment."[120] These challenges create a space for new designs and for innovation.

To address these challenges, Sparrow and Horan advocate a shift to "considering infrastructure elements as dynamic and evolving artifacts and moving [. . .] to a performance management orientation that utilizes IT to achieve high performance"[121] This idea, that information technology can better the performance of infrastructure by increasing feedback and response, is shared by some of the designers of DIY infrastructure. For example, initial development of Cloacina, a prototype dry sanitation system, attempted to decrease the need for water in sanitation by maximizing efficiency through information technology. This will be discussed at length in a subsequent section.

We can see examples of problems that arise as infrastructure becomes digital if we look at case studies describing specific infrastructures. In an analysis of the use of digital sensors in water treatment and delivery, Rae Zimmerman, a professor of planning and public administration and director of the Institute for Civil Infrastructure Systems, first

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120 Thomas Horan and Roy Sparrow, "Management Challenges," in *Digital Infrastructures: Enabling Civil and Environmental Systems Through Information Technology,* ed. Thomas Horan and Rae Zimmerman (New York: Routledge, 2004), 38.

121 Ibid. 52.

describes the ways that sensors are being used. Some examples are, "to gauge the rate of water flow (hydraulics), reactions for the removal of organic and inorganic substances including nutrients and pathogens, and associated use and behavior of raw input materials such as energy and oxygen. [122]" Sensors are not just used in measurement, they are used in analysis, for example, to determine "that social and economic goals are met […], to target upsets, anomalies, extremes and other deviations from normal or desired conditions. [123]" Of course, the use of sensors for analysis creates a problem in that "normal" conditions are not proscribed by sensors and software, they are proscribed by human regulators, therefore digital infrastructures have to "continuously adapt to changes in the way regulatory agencies and communities define quality objectives. [124]" Thus, this expectation that infrastructure can adapt has been wrought by the affordances of digital media. Because once constructed, large scale physical systems are difficult to reconfigure, the idea that imbricated, pre-digital water infrastructure adapts while in use would be untenable. The participatory affordance of digital media may generate expectations of adaptability that existing systems cannot deliver.

All of these new possibilities and challenges presented by digital infrastructure are important to any discussion of DIY infrastructure. There are two reasons for this. First, in evaluating DIY infrastructure projects, any comparison between them and other infrastructures requires an up-to-date portrait of the current state of those infrastruc-

[122] Rae Zimmerman, "Water," in *Digital Infrastructures: Enabling Civil and Environmental Systems Through Information Technology,* ed. Thomas Horan and Rae Zimmerman (New York: Routledge, 2004), 79.

[123] Ibid.

[124] Ibid.

tures. Because the use of digital media in infrastructure is currently changing traditional expectations and operations, these examples of digital infrastructure are necessary to ensure we can make accurate comparisons. Second, these new possibilities and challenges alter the design space in which designers of both DIY and traditional infrastructure operate. I will discuss this changing design space in a subsequent section. In the next section, I will discuss the relationship between infrastructure and political authority.

Non-Mechanical Factors

It's important to reiterate that the term "infrastructure" does not just refer to mechanical components, and that technologies exist as relationships with and between human and nonhuman actors. As we've seen in our discussion of the properties of infrastructure, they include "'hard' technologies ('ducts, pipes and wires'), 'soft' technologies (computer software, networks, and the World Wide Web), socio-technologies (bureaucracies, rules and procedures), human operators (including the challenging human-machine interface), and complex networks of relationships between the internal workings of the system and the outside environment in which it operates. [125]" Edwards elaborates on this, adding "socially communicated background knowledge, general acceptance and reliance, and near-ubiquitous accessibility [126]" to these criteria. These are especially appropriate, as they are not limited to objects–they include human and nonhuman actors and their dialogue with those objects. That dialogue is in flux and may include adaption to those ob-

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[125] Matthew Jude Egan, "Anticipating Future Vulnerability: Defining Characteristics of Increasingly Critical Infrastructure-like Systems," *Journal of Contingencies and Crisis Management* 15, no. 1 (2007): 6.

[126] Paul N. Edwards, "Infrastructure and Modernity," in *Modernity and Technology,* eds. Thomas J. Misa, Philip Brey and Andrew Feenberg, (Cambridge: The MIT Press, 2003), 188.

jects, including the possibility of their modification. For example, the designers of Cloacina, whose work is discussed at length below, contend with the ways that the toilets they design interface with the cultural norms of human waste disposal as much as they contend with the physical construction of toilets and the logistics of moving waste.

As Star and Bowker remind us, "infrastructure is not absolute. [127]" It exists in relationship to the conditions of its use, and "[i]t never stands apart from the people who design, maintain, and use it. [128]" Treating infrastructure as something purely material also poses the risk of eliminating the conceptual, intangible, or ephemeral. Like discussing hardware while neglecting to discuss software, this approach ignores the fact that the things listed above, including social organizations, technologies, affordances and expectations of service, all generate each other. This mutual generation does not require a centralized or deliberative authority.

In studying the means by which these mutually generating elements operate in German governmental workplaces, scholars like Volkmar Pipek and Volker Wulf center their research at the levels of the worker and organization. Pipek and Wulf argue that "the work infrastructure of a worker or organization is the entirety of devices, tools, technologies, *standards*, *conventions*, and *protocols* on which the individual worker or the collective rely to carry out the tasks and achieve the goals assigned to them. [129]" (Italics mine). Political theorist Jane Bennett examines these mutually generating elements while includ-

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[127] Susan Leigh Star and Geoffrey C. Bowker, "How to Infrastructure," in *The Handbook of New Media: Social shaping and social consequences of ICTs*, eds. Leah A. Lievrouw and Sonia Livingstone (London, UK: SAGE Publications, 2002), 230.

[128] Ibid.

[129] Volkmar Pipek and Volker Wulf, "Infrastructuring: Toward an Integrated Perspective on the design and Use of Information Technology," *Journal of the Association of Information Systems* 10, no. 5 (2009): 455.

ing a much wider range of actors. For example, in discussing the North American blackout of 2003, she argues that the electrical power system is an assemblage. While its parts are capable of coordinating to produce effects, that "coordination does not rise to the level of an organism." The components of the assemblage "include humans and their (social, legal, linguistic) construction," but they also include nonhumans: "electrons, trees, wind, fire, electromagnetic fields. [130]"

This is important because it challenges what Edwards identifies as an ontological separation between infrastructure and society. [131] There is a tendency to narrativize happenings involving infrastructure as either acts of god or the work of lone incompetents. Edwards gives the example of infrastructural disruptions typically being described "either as 'human error,' which codes the problem as individual and allows the assignment of blame, or as technological failure," when most would "be better explained by complex relationships among operators, systems, natural conditions, and social expectations."

Todd La Porte, a scholar of critical infrastructure and its resilience and disruption, provides some additional examples of these erroneous assumptions of agency in his discussion of the air travel system. "The remarkably low accident rates in commercial air transport […] reflect the success of vigilant organizations, legal apparatus, and social learning about accidents as much as they demonstrate the quality of aircraft design and maintenance. [132] Nevertheless […] people worry much more about the airplane than about

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[130] Jane Bennett, *Vibrant Matter: A Political Ecology of Things* (Durham: Duke University Press, 2010), 24.

[131] Paul N. Edwards, "Infrastructure and Modernity," in *Modernity and Technology,* eds. Thomas J. Misa, Philip Brey and Andrew Feenberg, (Cambridge: The MIT Press, 2003), 188-189

[132] Todd La Porte, "The United States Air Traffic System: Increasing Reliability in the Midst of Rapid Growth," in *The Development of Large Technical Systems*, eds. Renate Mayntz and Thomas Hughes, quoted in Edwards, "Infrastructure and Modernity," 190-191.

the ground crew, the Federal Aviation Administration, or air traffic controllers. Thus while infrastructure functions by seamlessly binding hardware and internal social organization to wider social structures, our commonsense perspective on infrastructure creates a "black box" that enables the rhetorical separation of society from technology in the modernist settlement. [133]"

Political Authority and Radical Monopoly

Infrastructure also stands as an embodiment of political authority. As an example, I'll begin with a highly uncontroversial statement: throughout history, humans have made choices about the location and expansion of their settlements in consideration of access to flows of matter vital to their survival. With regard to food, this means proximity to grazing land for domesticated animals and arable land for farming, or proximity to good areas for hunting and gathering. With regard to water, this means proximity to lakes, rivers, streams, natural springs, and the like.

The locations of those flows or coalescences of comestible matter place constraints on the locations of humanity. In the crudest terms, we can think of infrastructure as the artificial extension of humanity's reach to those vital materials–as an attempt to re-spatialize them. Decisions about the extension of that reach limit the space of other possible decisions. For example, if my government constructs an aqueduct between two locations, the time and resources required to do so may limit any subsequent ability or motivation to construct additional aqueducts. Furthermore, the construction of that aqueduct

[133] Paul N. Edwards, "Infrastructure and Modernity," in *Modernity and Technology,* eds. Thomas J. Misa, Philip Brey and Andrew Feenberg, (Cambridge: The MIT Press, 2003), 190-191.

changes the proximity of the populace to water, thereby changing the distribution of power.

Of course, no supply of water is infinite. If I reroute the flow of water I not only increase some people's access to it, I may decrease the access of others. So, this example, which overlooks politically charged questions of labor (the rights of the slaves building the aqueduct), and materials (how were the materials used in the construction of the aqueduct acquired – through force of arms, through trade?), shows that a decision about the placement of the aqueduct is a political one.

To make this point, Edwards paraphrases Langdon Winner when he writes "infrastructures act like laws. They create both opportunities and limits; they promote some interests at the expense of others. To live within the multiple, interlocking infrastructures of modern societies is to know one's place in gigantic systems that both enable and constrain us. The automobile/road infrastructure, for example, allows us to move around at great speed, but also defines where it is possible to go; only a few modern people travel far on foot to places where there are no roads. [134]"

By definition, infrastructure is an example of what Ivan Illich called a radical monopoly: a situation in which the ubiquity of a tool or service is so great that its use becomes compulsory, thus creating social control through design. [135] For example, the automobile possesses a radical monopoly in many cities like Los Angeles or Atlanta. As more design decisions are made to accommodate automobile traffic the radical monopoly

[134] Paul N. Edwards, "Infrastructure and Modernity," in *Modernity and Technology,* eds. Thomas J. Misa, Philip Brey and Andrew Feenberg, (Cambridge: The MIT Press, 2003), 191.

[135] Ivan Illich, *Tools for Conviviality* (New York: Harper & Row, 1973), 52-54.

of the automobile increases. Its widespread use may limit the ability to travel by other means.

We see examples of the relationship between infrastructure and political authority all of the time; in discussions regarding the funding of public transportation, for example. In that case, we might hear a number of subtle political arguments. Raising money to pay for public transportation might be viewed as penalizing (through taxes) those who feel they would not benefit from the system to confer advantages on those who will.

Of course, the radical monopoly of infrastructure means that regulation also arises as a consequence of its design. As Ivan Illich argued, radical monopoly "constitutes a special kind of social control because it is enforced by means of the imposed consumption of a standard product." Returning to the example of the automobile,

Resource Allocation

Let's look at three specific ways that infrastructure embodies political authority: as a signifier of the allocation of resources, as a platform for the generation of resources, and as a regulator of behavior.

Infrastructure is political in its expression of societal values because it serves as a conspicuous signifier of the way that a society allocates resources. The V.I. Lenin Order of Lenin Leningrad Metropoliten and the Dwight D. Eisenhower National System of Interstate and Defense Highways are distinct expressions of the cultures in which they are situated, embodying different ideas of universal access to transportation and different strategies for surviving a nuclear exchange.

Generation

Of course, infrastructure exists outside of the present tense. The allocation of today's resources–expressed through infrastructural development, maintenance or neglect–affects the development of future resources. Infrastructure may provide a substrate or platform for the generation of future resources. As such, those determinations also raise the issue of equitable distribution of resources. Here we can consider things such as the so-called "last mile problem," and the "digital divide." We could also consider the relationship of infrastructure to racial segregation–in assumptions about race, class and modes of transportation which affected urban development.

Regulation

In conjunction with the properties described above, the design of infrastructure can also function as a regulator of behavior. This thinking is as old as infrastructure itself. For example, in the article "Infrastructures and Societal Change, A View from the Large Technical Systems Field," Erik Van der Vleuten recalls that Proudhon "accused the French government of 'tending to turn a great nation, free until now, into a population of servants and serfs' through a 'monarchic and centralizing' railway network."[136] Whether or not Proudhon's assessment was correct, infrastructure can indeed function as a type of

[136] Erik Van der Vleuten, "Infrastructures and Societal Change. A View from the Large Technical Systems Field," *Technology Analysis & Strategic Management* 16, no. 3 (2004): 398.

invisible regulator. This can be deliberate, as in the case of "architectures of control" – a term referring to the regulation of behavior through the design of objects and systems as opposed to regulation through laws, norms, or market forces. For example, adding speed bumps to a busy street would be an attempt to control behavior through the design of the street itself, while lowering the speed limit on that street and or increasing its enforcement would be an attempt to control behavior through law. We can also consider so-called "tethered" digital devices–such as the Apple iPhone–which may need to be "jail broken" as compared to "open" or "generative" ones.

While he does not use the term "architectures of control," Bruno Latour explains the regulation of human behavior through the design of objects in his essay "Where are the Missing Masses? The Sociology of a Few Mundane Artifacts." [137] Therein, he describes a variety of objects, including devices which automatically return doors to a closed position, and the nagging alarms which persist when someone attempts to drive a car without fastening their seat belt. Latour refers to the range of behaviors that these devices make difficult as the excluded middle. While these examples are not drawn directly from the realm of infrastructure, they are important because they reveal the way that the design of mundane and often ignored objects constrains the range of actions available to us.

This is exemplary of Latour's work in teasing out the connections between objects and agency, and the way that that agency exists as part of a panoply of actors which include the human. While an exhaustive discussion of these concepts, known as the Actor-Network-Theory, would not be germane to this text, it is important to note the effects of

[137] Bruno Latour, "Where Are the Missing Masses? The Sociology of a Few Mundane Artifacts," in *Shaping Technology/Building Society: Studies in Sociotechnical Change*, eds. Wiebe E. Bijker and John Law (Cambridge: The MIT Press, 1994), 225–258.

objects–especially designed objects–on the behavior of other actors and entities. According to Latour, “Objects, by the very nature of their connections with humans, quickly shift from being mediators to being intermediaries, counting for one or nothing, no matter how internally complicated they might be. This is why specific tricks have been invented to make them talk, that is, to offer descriptions of themselves, to produce scripts of what they are making others–humans or non-humans–do.[138]” We can see how these sort of scripts can detail the regulatory effects of infrastructure and other designed objects and systems.

Whether this regulation is referred to as an “architecture of control,” or by the behavior it restricts–behavior occupying Latour’s “excluded middle,” an awareness of design as a regulatory force is necessary to understand infrastructure. Furthermore, that awareness informs and motivates many of the DIY infrastructure projects discussed later.

Infrastructure, Digital Media and Regulation

To investigate the relationship between infrastructure, digital media, and regulation, let’s return to a subject that rests more comfortably within typical discussions of digital media. We can take criticism of the primacy of the search engine as another example of these regulatory effects. As the search engine is one of the primary interfaces to information recorded on websites, sites that do not show up in search results can maintain a sort of de facto non-existence. In this example, the encyclopedic affordance of the computer is

[138] Bruno Latour, *Reassembling the Social: An Introduction to Actor-Network-Theory* (New York: Oxford University Press, 2007), 79.

tied to the agency of exclusion or inclusion. The word “democracy” could be removed from remote dictionaries via a system wide patch.

The Institutional Void

DIY infrastructures are responses to a void left by traditional political and institutional responsibilities–and that void may be the same place that digital media and imbricated municipal infrastructures meet. It relates to a wider unavailability of funds for infrastructure creation and maintenance. In our current political climate, “Keynes” is a four letter word and austerity is widely touted as a solution to national debt crises. In some cases municipalities are resorting to selling infrastructure which was publicly owned to private companies. DIY infrastructures are utopian projects, steps toward a future in which local innovation emerges where the stewards of public and private infrastructure sit idle.

Additionally, DIY innovators and grassroots responders can operate outside of existing institutional frameworks, working around or ignoring the impediments they create. We can see this as a specific application of critical making practices, where DIY infrastructure’s developers are empowered by things like knowledge sharing via the web; software tools; and cheap, easily programmable micro controllers.

Furthermore, the groups developing these projects often operate outside of the purview of the stewards of existing infrastructural systems and may be willing to investigate and discuss solutions that would not otherwise be considered. For example, Cloacina promotes the use of waterless toilets, something existing municipal water and sewage authorities may be unwilling to discuss because of problems with interfacing with legacy systems.

Political Scientist Maarten Hajer characterizes the need to look beyond existing institutional frameworks as follows:

> More than before, solutions for pressing problems cannot be found within the boundaries of sovereign polities. As established institutional arrangements often lack the powers to deliver the required or requested policy results on their own, they take part in transnational, polycentric networks of governance in which power is dispersed. The weakening of the state here goes hand in hand with the international growth of civil society, the emergence of new citizen-actors and new forms of mobilization. In such cases action takes place in an "institutional void": there are no clear rules and norms according to which politics is to be conducted and policy measures are to be agreed upon. To be more precise, there are no generally accepted rules and norms according to which policy making and politics is to be conducted. [...] The argument that policy making often takes place in an institutional void does not suggest that state-institutions and international treaties have suddenly vanished or are rendered meaningless. The point is rather that we can observe that there are important policy problems for which political action either takes place next to or across such orders, thus challenging the rules and norms of the respective participants. [139]

[139] Maarten Hajer, "Policy without polity? Policy analysis and the institutional void," *Policy Sciences* 36, no. 2 (2003): 175-195.

DIY infrastructure projects are often an attempt to occupy this institutional void. In many cases, they operate in a no-man's land between the maintainers and regulators of sanctioned infrastructures and activists and designers working as part of a new interconnected and global civil society.

Ironically, this interconnected global civil society is supported by the same infrastructures responsible for the splintering of urban areas worldwide. As geographers Stephen Graham and Simon Marvin argue in their book Splintering Urbanism: Networked Infrastructures, Technological Mobilities and the Urban Condition, digital media, information and communication technologies, other technological shifts, and the privatization of infrastructure, are responsible for this splintering. Here we see things like "premium and secessionary networked infrastructure,[140]" in which the services provided through infrastructure may be tiered or segregated in their delivery. This stands in contrast to historical precedents of universal service provided by state sanctioned monopolies.

In their awareness of and interaction with the complex relationships between digital media, infrastructure, and political authority, DIY infrastructure's designers are attempting to intervene in this space and articulate a new relationship between design and infrastructure. It is a relationship which displays a new cognizance of the ways that existing infrastructure constrains and supports design action. For example, the designers of Cloacina must analyze and anticipate all of the expectations and constraints of our existing sanitation infrastructure in addition to designing a new service and the products which support it. At the same time, Kate Rich, the designer of Feral Trade Courier, a DIY ship-

[140] Stephen Graham and Simon Marvin, *Splintering Urbanism: Networked Infrastructures, Technological Mobilities and the Urban Condition* (New York: Routledge, 2001), 385.

ping logistics project also discussed in a later chapter, calls upon existing transportation infrastructure in developing an alternative shipping system built upon social networks.

Infrastructure, Design, and Political Authority

Infrastructure's embodiment of political authority also affects its relationship to design. The properties of infrastructure discussed in this section further reveal the role of design as a regulatory force and its role in constructing infrastructure's radical monopoly. Since the design of infrastructure regulates human behavior, it also regulates designers. I hope to reveal some of the overlooked constraints that the radical monopoly of infrastructure places on designers–the way that age-old design decisions harden into expectations and protocols and limit new solutions.

Infrastructure both supports and constrains design action. In the first case, it is a system of imbricated technologies and artifacts which provide a substrate for new product and services. Designers creating new electrically powered projects–a lamp, for example–do not need to design a system of generating, distributing or regulating electricity. They need only ensure that the products they design are compatible with the system that already exists.

In the second case–the converse of the first–designs are limited by existing infrastructure. Newly designed products and services have to interface with existing infrastructure, and are therefore beholden to the legacy of design decisions which resulted in that infrastructure. Designers have to contend with the complex social, political and economic results of past design decisions which are embodied in infrastructure.

As an example of the significance of infrastructure to the designer, let's continue discussing the design of a lamp. While a designer shapes a lamp's formal properties in terms of overlapping criteria such function, aesthetics, and a consideration of the cost of its components, assembly, packaging and shipping, a consideration of its interconnection with the electrical infrastructure may require very little thought outside of specifying the appropriate components for the country in which the lamp will be plugged in. The designer operates under the assumption that once the lamp is designed to interface correctly with the electrical system of a particular place, that electricity will be supplied. The degree to which the designer does not have to consider the electrical system speaks to the ubiquity and invisibility of infrastructure.

Nonetheless, the electrical infrastructure, itself an agglomeration of years of design decisions, is absolutely necessary for the lamp to function. Infrastructure limits the scope of design action. It separates what may be considered reasonable–designing a lamp–from something that may not be considered at all–redesigning the grid.

Infrastructure limits future design possibilities through path dependence. Standards emerge after a user base exceeds a critical mass and these standards create increasing pressure for designers to comply with them. New designs are constrained by the expectation of being interoperable with existing designed systems, even if those systems were designed poorly, or designed to address problems we now have new information about. For example, many products were designed as if the resources required to power them would also be cheap and plentiful, and as if their use would not alter the environment in which they operate.

Infrastructuring

While those are ways that infrastructure may constrain design at large, the design *of* infrastructure presents even more difficulties. Because infrastructure includes social and regulatory elements in different and sometimes fluctuating configurations, it is difficult to assign jobs to its users and maintainers before the fact. According to Star and Bowker, "[t]he design implication here is that there is no possible a priori assignation of tasks […] the emergent infrastructure itself represents one of a number of possible distributions of tasks and properties between hardware, software and people." [141] Designers are not only limited by infrastructure; the complex social configuration surrounding infrastructure is one of the things which make it difficult to design:

> The infrastructure designer must always be aware of the multiple sets of context her work impinges on. Frequently a technical innovation must be accompanied by an organizational innovation in order to work: the design of sociotechnical systems engages both the technologist and the organizational theorist. [142]

So, as we shall discuss in a subsequent section, designers of sanitation infrastructure are not only designing toilets and sinks, they are contending with entrenched norms and habits of use. Pipek and Wulf describe these considerations as being absent from design methodologies:

[141] Susan Leigh Star and Geoffrey C. Bowker, "How to Infrastructure," in *The Handbook of New Media: Social shaping and social consequences of ICTs*, eds. Leah A. Lievrouw and Sonia Livingstone (London, UK: SAGE Publications, 2002), 232.

[142] Ibid. 233.

> Design methodologies require designers to define a design scope (for example, a particular device or software artifact). Doing this requires defining what is internal (things to modify/design) and what is external (issues to consider) to a design process [143] […] the complexity of the work infrastructure makes this a difficult and error-prone process that may require corrections later.

However, many of these decisions regarding scope, decisions about what is or is not the object of design or internal to its design, are not formalized. Pipek and Wulf continue "[t]hese decisions often remain implicit and are usually not part of a design methodology. [144]" He adds that designers need to determine which (if any) standards to ignore or consider. [145]

Pipek and Wulf also remind us that infrastructure supports design, often using the phrase "work infrastructure" to refer to infrastructure that people use in taking care of their day -to-day responsibilities. Drawing on the property of transparency described by Star, Pipek and Wulf question the ability of workers to identify the transparent or invisible infrastructures they rely on to do their work: "The (in)visibility of a work infrastructure makes it hard for users to be fully aware of their own work procedures, making it difficult for designers to elicit requirements, and making it more likely that a technological solution will need several iterations of evaluation and design improvement before it is considered useful. [146]" Pipek and Wulf's argument has two ramifications for the design of

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[143] Volkmar Pipek and Volker Wulf, "Infrastructuring: Toward an Integrated Perspective on the Design and Use of Information Technology," *Journal of the Association of Information Systems* 10, no. 5 (2009): 449.

[144] Ibid.

[145] Ibid.

[146] Ibid.

infrastructure. First, it refers to the problems designers–especially software designers–may face because they need to determine the relationship of their designs to the work infrastructure of their users. Second, it erodes boundaries between design and use: users ultimately determine much of the way that a new design will interface with their existing work infrastructure, and Pipek and Wulf feel that this is a kind of design by itself. He argues that "the strict methodological separation of design and use represents a core problem of IS design. The term design may even be misleading, as it focuses on an artifact that should be designed, and neglects the surroundings into which the artifact is placed, which remain in focus when we discuss infrastructures. [147]" So, not only is designing both constrained and supported by infrastructure, infrastructure blurs the boundaries between design and use.

[147] Ibid. 452.

4. SHARED TRAITS

Before proceeding to case studies of particular DIY infrastructure projects, I would like to draw from previous chapters and present a set of shared traits of DIY infrastructure projects for the reader to keep in mind when those projects are discussed in detail. While the projects covered in later chapters may exhibit these traits to varying degrees, they are all present.

First, DIY infrastructure projects involve thinking about and designing infrastructure as a system and not just in terms of its constituent components or relationships. DIY infrastructure designers are not just attempting to design toilets or routers or shipping databases, they are attempting to design sanitation systems, telecommunication systems and shipping systems of which toilets, routers, and databases are parts. This sort of thinking is difficult as infrastructure as an object of design can be so complex that it may be unidentifiable when viewed at certain scales. For example, Herbert Simon's approach of studying design problems in terms of the parameters of the inner environment and the constraints of the outer environment is problematic because within the domain of infrastructure these constraints and parameters are hard to distinguish from each other, and they may even influence each other reciprocally.

Because of this need to think of infrastructure as a system, and not just in terms of the objects and relationships that comprise it, DIY infrastructure designers and their work necessarily unveil infrastructure's operation. So, part of their project is a reversal of Star's property of transparency, that infrastructure is only revealed when it ceases to function properly[148]. As such, all of the projects discussed in the following sections are attempts to take infrastructure out of its black box and move it from the realm of the distant and abstract into a space of both personal fascination and personal responsibility.

This is called infrastructural inversion, a term first introduced by Geoffrey Bowker, and discussed in detail by Bowker and Star. According to them, infrastructural inversion "is a struggle against the tendency of infrastructure to disappear (except when breaking down).[149]" They describe infrastructural inversion as a "gestalt switch," employing a figure-ground inversion.[150] Edwards describes the process of infrastructural inversion: "You turn it upside down and look at the 'bottom'—the parts you don't normally think about precisely because they have become standard, routine, transparent, invisible. These disappearing elements are only figuratively "below" the surface, of course [...] But as with anything that is always present, we stop seeing them after a while[151]."

For scholars of digital media, infrastructural inversion has special significance. Digital media scholarship often focuses on establishing a series of properties of digital media artifacts and using those properties to analyze specific artifacts. For example, Manovich establishes a series of properties of digital media, such as numeric representation and

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[148] Susan Leigh Star, "The Ethnography of Infrastructure," *American Behavioral Scientist* 43, no. 3 (1999): 381.

[149] Geoffrey C. Bowker and Susan Leigh Star, *Sorting Things Out: Classification and Its Consequences* (Cambridge: The MIT Press, 2000), 34.

[150] Ibid.

[151] Paul N. Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming* (Cambridge: The MIT Press, 2010), 20.

modularity, and uses them to discuss the interfaces and operations of image editing software[152]. Digital Media studies often focuses on digital artifacts and systems of art and entertainment such as video games, virtual worlds and new types of interfaces to existing content. While these are all worthwhile pursuits, many of the digital media artifacts and systems which inform and undergird our day-to-day lives are often neglected as objects of study. Many of these objects and systems rest within the domain of infrastructure. As I discussed above, the increasing addition of digital devices such as sensors and wireless networking equipment to existing infrastructure only increases the need for its evaluation by digital media scholars.

Next, and as the name implies, DIY infrastructure projects are not the work of paid professionals, and are not primarily motivated by profit.[148] Many of these projects are being undertaken by amateurs or people working outside of their areas of expertise. For example, Kate Rich, the designer behind the Feral Trade Courier project, had no professional experience with shipping or logistics before beginning. The fact that these projects are often non-commercial and pursued by concerned designers, artists and activists instead of industry insiders is tied directly to the last trait, which reveals the position of the DIY infrastructure designer as something antagonistic to the interests of many existing infrastructure operators.

DIY infrastructure projects are attempts to address some sort of problem their designers have identified with the status quo in issues such as border control, resource depletion, or affordable access to communication technology. In all cases discussed within this

[152] Lev Manovich, "Inside Photoshop," *Computational Culture* 1 (2011), accessed January 14, 2013, http://computationalculture.net/article/inside-photoshop.

document, the radical monopoly of infrastructure itself becomes one of these issues, and DIY infrastructure designers attempt to offer alternatives to what they view as monolithic or monopolistic systems. DIY infrastructure projects are in part a response to the alleged irreversibility of large-scale public works and their consequences, and may be a response to a void between the interests of infrastructure's owners and operators and its users. As such, DIY infrastructure projects may operate outside of existing institutional frameworks, working around or ignoring the impediments they create.

In addition to the traits these projects share, each of them has something particular to teach us about the design of DIY infrastructure, and I highlight these things in the case studies that follow. Feral Trade Courier exposes the role of the social and the subjective in the design of logistics systems. Village Telco and Fluid Nexus show us that the relationship between established infrastructure and DIY infrastructure can be both complementary and antagonistic, and present the design of new channels of communication as additions to an ecosystem of technologies. Cloacina provides us an example of a way that DIY infrastructure might scale up and effect lasting sociotechnical change. After a short discussion of process, I analyze each of these projects in turn.

5. METHOD

Digital media studies is a comparative practice in which digital media artifacts are identified and analyzed according to different frameworks. For example, and as discussed previously, Murray discusses digital media in terms of encyclopedic, procedural, spatial, and participatory affordances.[153] These are the affordances I explained previously in discussing Smart Pigs systems.

I also discussed the work of Manovich, who describes a new media object as having the following properties: numerical representation, modularity, automation, variability, and transcoding.[154] I used this framework earlier when discussing MISO data displayed online.

What is different about my work is that I am using these frameworks from digital media studies to examine things that digital media studies typically does not. These frameworks are most often used to analyze digital media in the realm of art and entertainment such as video games, interactive narratives, and image manipulation software. The study of infrastructure, and the relationship of digital media and infrastructure is often uninformed by the insights of digital media studies. This is an oversight in two ways: First, scholars in what is broadly termed public policy, including those studying resilience

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[153] Janet Murray, *Inventing the Medium* (Cambridge: The MIT Press, 2011), 56.

[154] Lev Manovich, *The Language of New Media* (Cambridge: The MIT Press, 2002), 27-48.

and critical infrastructure, can benefit from the frameworks that digital media studies provides. Those frameworks can help describe the ways that digital media interfaces with infrastructure, and articulate the effects of those hybrids in ways that more easily convey their significance. Second, the almost exclusive focus of digital media studies on art and entertainment means that digital media's role in supporting the infrastructure of our everyday lives is going ignored. This extends beyond infrastructure such as power generation, telecommunication, transportation and sanitation discussed in this document and includes digital media's role in facilitating global banking and finance, human resources, and health care management.

DIY infrastructure projects are developing in technological niches and there is not a lot of information about them outside of the websites of DIY infrastructure designers. While these websites were certainly valuable, they often focused on goals and problem formation more than they detailed processes. Because of this it was necessary to conduct firsthand interviews with those designers who were willing correspondents and stubbornly pursue those who were not. While this section provides an account of my process, I also feel that it documents some of the interplay and attitudes among different DIY designers and communities, many of whom were quick to direct me to the work of others.

I contacted Kate Rich of the Feral Trade Courier project in January of 2012, and interviewed her via Skype in February of 2012. I also corresponded with her through email with follow up questions.

I interviewed Nick Knouf of the Fluid Nexus project in March of 2012, and I contacted David Rowe of Rowetel, one of the designers of the Mesh Potato–an open source mesh networking device used by Village Telco–in January of 2012. He agreed to an interview through email, and I sent him a set of questions. In March of that year he responded to a follow-up email saying that he would reply soon. I did not hear from him again. I was, however, able to interview Steve Song of Village Telco over Skype in February of 2012.

The Cloacina project was first brought to my attention by Liam Rattray of Arkfab, an Atlanta, Georgia project working on projects in urban food production. I then spoke to Molly Danielsson of Cloacina over email and by telephone and arranged to observe and interview her and Matthew Lippincott in the Portland, Oregon area in October of 2011. During this trip I observed the deployment of a portable dry sanitation system they had developed with assistance from their students in the Pacific Northwest College of Art's master's program in collaborative design. During this time I was able to interview participants, and observe and photograph construction, removal, and system maintenance. I also attended a post deployment class critique attended by a representative from a local sustainable sanitation advocacy group. This trip culminated in a longer interview with Lippincott and Danielsson, and I've had continued contact with them. They offered advice in attempting to secure interviews with participants of the Open Source Ecology project, and I was in contact with them in reference to their participation in the exhibition "Constructive Interference," which ran from March 19 to May 16, 2012 at Emory University.

6. DIY TRANSPORTATION LOGISTICS

This chapter discusses Feral Trade Courier, a project in which freight is moved over social networks. The project's primary goal is to reveal the human and social components of shipping and logistics. These often obscured social components are key not just to Feral Trade, but to the design and operation of the other DIY infrastructure projects I discuss in later chapters. As part of this revelation of the social, Feral Trade is also noteworthy in exposing the sometimes contentious relationship between DIY infrastructure designers and entrenched interests such as government regulators. I begin the chapter with an overview of Feral Trade Courier and the project's goals.

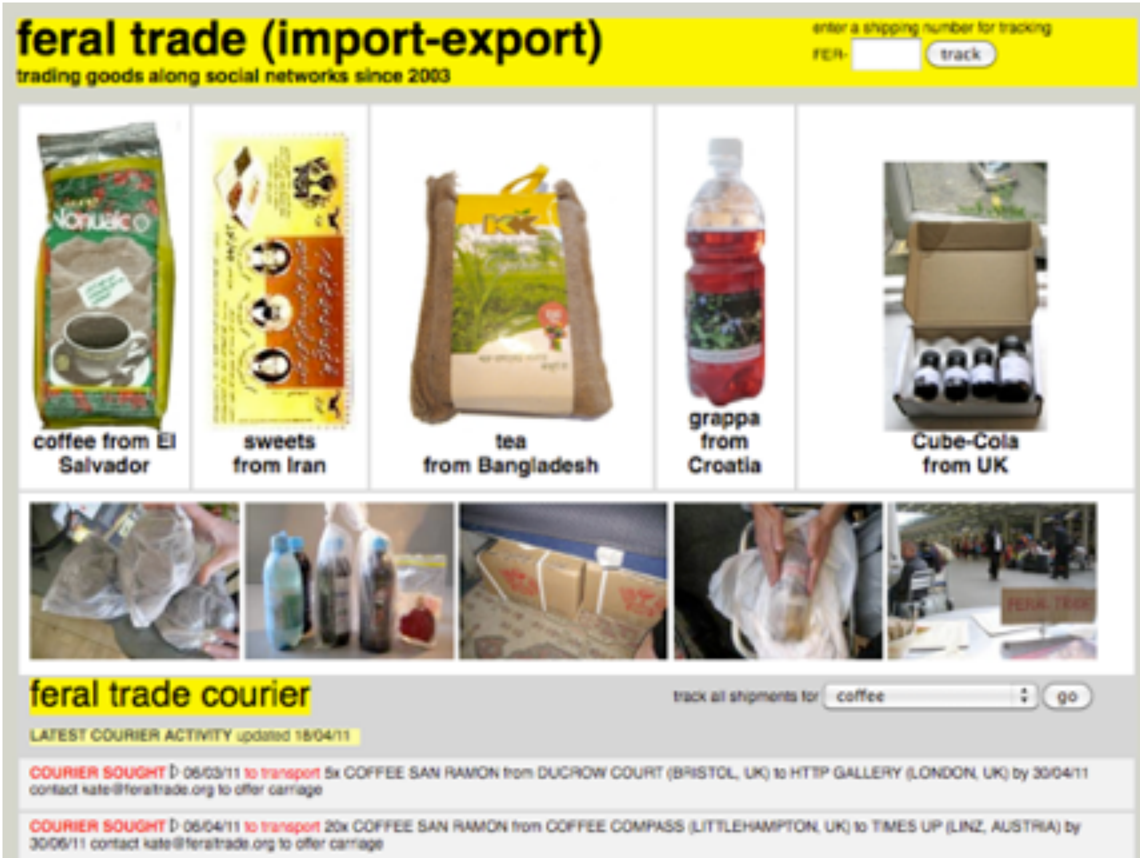

Figure 12. Screenshot of Feral Trade Courier website

(http://www.feraltrade.org/cgi-bin/courier/courier.pl, accessed May 5, 2011.)

Feral Trade Courier is a project of Australian born and London based artist Kate Rich. Described as "a public experiment trading goods over social networks.[155]" Kate's earlier work was as a part of the Bureau of Inverse Technology with Natalie Jeremijenko, and she is also one of the two artists involved with "Cube Cola," the open-source soft drink project. Feral Trade Courier includes "a live shipping database for a freight network running outside commercial systems. The database offers dedicated tracking of feral trade products in circulation, archives every shipment and generates freight documents on the

[155] "Feral Trade Products Passed by Hand," *Feral Trade*, accessed May 5, 2011, http://www.feraltrade.org/statement/.

fly [156]." This is a database "handcrafted by the artist, [in which] couriers log their journeys. [It] forms the sole physical infrastructure for an alternative freight network, which operates without any material assets (vehicles, staff, communications devices, depots)." Drawing upon the encyclopedic affordance of digital media [157], "It enables producers, couriers and buyers to track not only the transit of their own produce but all grocery movements in the network; outputting waybills that document the details of sources, shipping and handling with the kind of microattention that ingredient listings normally receive. [158]" In short, Feral Trade Courier repurposes the type of computer aided logistics infrastructure underpinning the flow of material around the globe and uses it to support an experiment in using an existing social network to transport goods.

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[156] "Feral Trade Courier," *Feral Trade*, accessed May 5, 2011, http://www.feraltrade.org/cgi-bin/courier/courier.pl.

[157] Janet Murray, *Inventing the Medium* (Cambridge: The MIT Press, 2011), 70.

[158] "Http Gallery," *HTTP*, accessed May 5, 2011, http://www.http.uk.net/.

feraltrade courier

all shipments for coffee

awaiting transit or enroute			Reports			
ID	Qty	Shipment	Requested to Ship	waybill	freight	invoice
FER-1582	5	coffee San Ramon from Ducrow Court to Materials & Applications	betw. 26/02/11 & 27/05/11			
FER-1583	2	coffee San Ramon from Ducrow Court to Fell Street	betw. 02/03/11 & 02/06/11			
FER-1584	5	coffee San Ramon from Ducrow Court to Bristol Blue Glass	betw. 02/03/11 & 02/04/11			
FER-1586	2	coffee San Ramon from Ducrow Court to Tate Modern	betw. 06/03/11 & 20/04/11			
FER-1587	5	coffee San Ramon from Ducrow Court to HTTP gallery	betw. 06/03/11 & 30/04/11			
FER-1596	20	coffee San Ramon from Coffee Compass to Times Up	betw. 06/04/11 & 30/06/11			
FER-1597	2	coffee San Ramon from Ducrow Court to Collective Gallery	betw. 06/04/11 & 14/04/11			

delivered			Reports				
ID	Qty	Shipment	Shipped	Delivered	waybill	freight	invoice
FER-1607	5	coffee San Ramon from Ducrow Court to Burghley Rd	08 Apr 11	18 Apr 11			
FER-1589	15	coffee San Ramon from Ducrow Court to cremer street	07 Apr 11	(sameday)			
FER-1590	1	coffee San Ramon from Environmental Health Clinic to Moon in the Pond Farm	18 Mar 11	(sameday)			
FER-1585	5	coffee San Ramon from Ducrow Court to Environmental Health Clinic	28 Feb 11	(sameday)			
FER-1581	15	coffee San Ramon from Ducrow Court to Cube Microplex	25 Feb 11	(sameday)			
FER-1580	60	coffee San Ramon from Coffee Compass to Ducrow Court	23 Feb 11	24 Feb 11			
FER-1579	205	coffee San Ramon from San Ramón to Coffee Compass	14 Feb 11	21 Feb 11			
FER-1547	1	coffee Nonualco from Ducrow Court to stoke newington international airport	20 May 10	20 Jun 10			
FER-1560	3	coffee Nonualco from Tyneside Cinema to Castlefield Gallery	10 Jun 10	12 Jun 10			
FER-1536	12	coffee Nonualco from Cube Microplex to Tyneside Cinema	29 Jan 10	01 Feb 10			
FER-1507	3	coffee Nonualco from HTTP gallery to Istanbul	03 Sep 09	09 Sep 09			
FER-1506	3	coffee de la sierra from Consorcio APICAFE to Rosebery Avenue	17 Jul 09	22 Jul 09			
FER-1471	3	coffee Nonualco from Cube Microplex to Toronto airport	18 Feb 09	18 May 09			
FER-1491	7	coffee Nonualco from Cube Microplex to HTTP gallery	13 May 09	15 May 09			
FER-1487	4	coffee Nonualco from Cube Microplex to Futuresonic	06 May 09	13 May 09			
FER-1486	5	coffee Nonualco from Cube Microplex to Cube Microplex	07 May 09	(sameday)			
FER-1479	5	coffee Nonualco from Cube Microplex to Bristol Blue Glass	17 Feb 09	(sameday)			
FER-1466	10	coffee Nonualco from FoAM to Nadine	23 Jan 09	(sameday)			
FER-1461	15	coffee Nonualco from Cube Microplex to FoAM	20 Jan 09	(sameday)			
FER-1407	5	coffee Nonualco from Ambient TV to Porapara Space for Artists	05 Aug 08	03 Jan 09			
FER-1413	8	coffee Nonualco from FoAM to Times Up	22 Nov 08	22 Dec 08			

Figure 13. Screenshot of shipping manifest from Feral Trade Courier website (http://www.feraltrade.org/cgi-bin/package/2package.pl?action=display_product&new_sort=goods&criterion=coffee, accessed May 5, 2011.)

The first shipment delivered through this process was approximately 65 pounds of coffee from the Sociedad Cooperativa of San Pedro Nonualco, El Salvador to the Cube Microplex, a cinema in Bristol, UK. This shipment was arranged through existing social networks over email and SMS [159]. The coffee was then traded further into Europe by the same process, "harnessing the surplus freight potential of recreational, commuter and cul-

[159] "Feral Trade Products Passed by Hand," *Feral Trade*, accessed May 5, 2011, http://www.feraltrade.org/statement/.

tural travel for the practical circulation of goods.[160]" Feral trade soon expanded to include the shipment of good such as Croatian brandy, Bangladeshi tea, and Iranian candy [161].

Motivation

According to the curators at North London's http gallery[162], Feral Trade –Rich's work– "provides a convivial setting from which to contemplate broader changes to our climate and economies, where conventional supply chains (for food delivery and cultural funding) could go belly up.[163]" Kate Rich claims she was motivated to look for "wormholes and loopholes"[164] in what she felt was the "inevitability of having to use [international express mail carrier] DHL." She was also frustrated that a product marketed and sold according to the means by which it is produced–fair trade coffee–was distributed through an opaque system which did not allow a consumer to trace back or confirm the conditions of its production. As she puts it, "it's got a picture of a farmer on it but there's no picture of how it got there [or of] all of the other relationships involved in its purchase and transformation into a product on the shelf." This opacity results from what geographer Stephen Graham has called the dyadic relationship between software and geography.

According to Graham, this relationship increasingly allows the affluent to:

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[160] Ibid.

[161] Ibid.

[162] "About," *Furtherfield*, accessed May 5, 2011, http://www.furtherfield.org/content/about.

[163] "Http Gallery," *HTTP*, accessed May 5, 2011, http://www.http.uk.net/.

[164] Kate Rich, interview with Jonathan Lukens, Skype, February 28, 2012. All remaining quotations from Rich come from this interview unless otherwise noted.

> Further their secession from the wider space-times of the city, as they seek to locate in, and consume, the privileged, best serviced and highest amenity neighborhoods. The algorithms that support such choices, simulations, orderings, and classifications […] remain completely opaque and utterly unscrutinized. [165]

Databases full of consumer data such as credit history and spending habits are associated with spatial data; the locations of consumers and their purchases are mapped. This confluence of data and location is typically invisible to consumers themselves. As I shall describe, Feral Trade addresses the opacity of automated global shipping through the detail and content of its labels and documents. It does this in two ways. First, as consumer's purchase history generates a "data-body" [166] or "capta-shadow" [167], Feral Trade generates an alternative, accessible, and even conversational record in which consumption and transportation of goods is less segregated. Second, Feral Trade exposes software as a regulatory force through the creation of its own software, which does not privilege the qualitative over the anecdotal. Capta-shadow and geolocation become personal, narrative, and biographical. This design choice is an attempt to invert our usual relationship with infrastructure. Instead of delivery people as nameless faces in matching uniforms, part of a larger enterprise of infrastructure as brand, we see personal observation, foibles, and commentary. Some of the ways these are revealed are through Feral Trade's labeling and

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[165] Stephen Graham, "Software-sorted geographies," *Progress in Human Geography* 29, no. 5 (2005): 562–580.

[166] "The data body gives them [marketers] insights into consumption patterns, spending power, and "lifestyle choices" of those with surplus income. The data body helps marketeers find you, and provide for your lifestyle." Critical Art Ensemble, *Flesh Machine* (New York: Autonomedia, 1998), 146, http://www.critical-art.net/books/flesh/flesh7.pdf.

[167] Martin Dodge and Rob Kitchin, "Codes of Life: Identification Codes and the Machine-Readable World," *Environment and Planning D: Society and* Space 23, no. 6 (2004): 854.

database. I discuss both in detail below. The encyclopedic and procedural affordances of digital media allow for their creation as much as they allow for typical FedEx and UPS waybills, we are just not used to those affordances being called upon in this fashion or in this context.

Anecdotal and Quantitative

These affordances are also evident in the packaging created for goods transported over the Feral Trade network. According to the artist statement for the Feral Trade Courier project, "[d]esign and production of documentary product packaging is an integral part of the feral trade process, with a view to rendering details of source, shipping and handling [168]." We can access the feral trade website and see this for ourselves. In figure 14, we see the record for a delivery of feral trade coffee San Ramon, grown in San Pedro Nonualco, El Salvador, as it was transported from Ducrow Court in Bristol, UK to Weserstrasse, Berlin, Germany. A horizontal band of photographs shows (from left to right) where the coffee was grown, the coffee in its package, the shipment's point of origin, and its destination. We can see how the product was conveyed over Kate Rich's social network by looking at the summary field at the top. There, in the black bar across the top of the package, is the following information: "Facilitated for Feral Trade by US Peace Corps husband and wife Helen Cold and Matt Federbar in San Ramon." In addition, the remarks field includes "direct via cube sound tech lea piontek's friend visiting Bristol in may."

[168] "Feral Trade Products Passed by Hand," *Feral Trade*, accessed May 5, 2011, http://www.feraltrade.org/statement/.

The coffee was transported from Bristol to Berlin, by a friend of a sound technician who works at Cube, a Bristol arts space.

Unlike the shipment information we are accustomed to seeing when tracking a package on the website of a courier like FedEx or UPS, which would display information from a package's shipper to receiver, this Feral Trade waybill includes a "Total Route" field, which delineates the *entire* distance traveled by the product extending back to the site of its production. For example, the shipment of coffee San Ramon discussed above has a total route from San Ramon in San Pedro Nonualco, El Salvador to the San Salvador airport to the Atlanta, Georgia airport to London-Gatwick airport to London-Heathrow airport to Coffee Compass coffee roasters in Ducrow Court, Bristol, UK to Cube Microplex cinema in Bristol, UK to the Bristol bus station to the Bristol airport to Berlin Schoenefeld airport to Friedrichshain to Weserstrasse.

Figure 14. Detail of a location within the Feral Trade database (http://www.feraltrade.org/cgi-bin/package/2package.pl?action=format_waybill&edit_id=1668, accessed Friday, September 14, 2012.)

We see a similar expression of details normally left out of the purview of customers in the "Shipping Facts" label created and affixed to each bag of Feral Trade coffee. These labels enumerate what would typically be hidden costs to the consumer such as customs clearance fees, freight agent handling fees and incidental transportation costs. For example, the label reproduced in figure 15 is divided into three columns. The left column displays either a good (such as coffee beans) or a service (such as airport parking), the middle column displays the gross cost, and the right column displays the cost per unit. From top to bottom, the left column includes the following items: 287 pounds of coffee beans, ground transportation from San Ramon to San Salvador, Delta Airline cargo fees, packaging materials, airport parking, a Western Union money transfer fee, customs clearance, a freight agent handling fee, ground transportation from Heathrow to Littlehampton, the cost of roasting the coffee beans, and the cost of estimated delivery of a bag within the UK.

Figure 15 Labeled Café San Ramon (http://www.feraltrade.org/goods_image/1088.jpg, accessed Friday, September 14, 2012.)

The thinking behind Feral Trade is summed up at the bottom of this “Shipping Facts” label, and on a small text field on the left side of the next portion [169] of the waybill discussed above. It reads “onward freight via social/cultural baggage: the following delivery costs are not reflected in product price but harness the surplus freight potential of social & cultural traffic for the distribution of goods.”[170] Note that the label is a one-off, and unique to this particular bag of coffee–shipment # FER-1580– which traveled from Coffee Compass coffee roasters to Ducrow Court, Bristol UK.

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[169] “Feral trade coffee San Ramon,” *Feral Trade*, accessed September 14, 2012, http://www.feraltrade.org/cgi-bin/package/2package.pl?action=format_waybill&edit_id=1668.

[170] Ibid.

Figure 16. Courier reports from the Feral Trade Courier database (http://www.feraltrade.org/cgi-bin/package/2package.pl?action=format_waybill&edit_id=1668, accessed Friday, September 14, 2012.)

In addition to recording of distances, times, and locations, Feral Trade waybills also include anecdotal information. For example, in the following [171] image, taken from the same Feral Trade waybill, the text reads:

> She had her maiden name for the transfer which did not match her government ID. Cycled back to the Money Shop and waited in line with all the end of month paycheck advance customers, eventually showed the counter clerk my photo-ID and got the name change. SMS from Helen at SAL with shipment success and the Delta airwaybill number for tracking. Back home I phoned Kingscote Freight at LHR to intercept the shipment on arrival. As I don't have a fax machine, I had to email Kingscote a request to World Freight Services to hand the shipment over to Kingscote on arrival, which they then faxed to World Freight Services. [172]

These types of events, extra trips to correct discrepancies between names and IDs and additional phone calls to compensate for not having a fax machine may be part of the experience of many people, but are not what we expect when dealing with the normally opaque processes of the shipment and receipt of goods. These anecdotal accounts reveal human behavior bumping up against regulatory structures and technological arrangements. Accounts of these events are not available from typical courier services or freight companies. While they may or may not occur in the operation of those services or companies, the significance of these anecdotes is not that they reveal any sort of hidden activity at a company like FedEx or DHL. Their significance is in their revelation of the nu-

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[171] "Feral trade coffee San Ramon," *Feral Trade*, accessed September 14, 2012, http://www.feraltrade.org/cgi-bin/package/2package.pl?action=format_waybill&edit_id=1668.

[172] Ibid.

merous human transactions and relationships required to move objects around the world. This allows us to recontextualize human agency as a part of the global flow of material, energy, and information discussed in chapter one, tying the abstraction of flow to the mundanity of thousands of bureaucratic encounters.

Figure 17. Courier reports from the Feral Trade Courier database (http://www.feraltrade.org/cgi-bin/package/2package.pl?action=format_waybill&edit_id=1668, accessed Friday, Sept. 14, 2012.)

Furthermore, within Feral Trade's database, individuals and organizations are not differentiated. For example, by accessing the Feral Trade database through http://feraltrade.org, and pulling up the entry for Weserstrasse (figure 18, below), the destination for the shipment of coffee discussed above, we not only see a graph of nodes through which Feral Trade goods passed, but a list of all couriers which have transported goods to Weserstrasse. These include individuals (Lea Piontek, Matt Federbar), airlines (Delta Airlines), and Freight Agents (World Freight Services). This is another example of Feral Trade's reversal of the typical relationships within freight services. Instead of the work of individuals receding into the invisibility of infrastructure, it remains undifferentiated from that of collections of individuals. This prevents individual agency from being obscured.

All of this anecdotal and quantitative date information noted by Feral Trade couriers and recorded in the Feral Trade database was presented to the public at Feral Trade Café, a temporary installation in which patrons were able to purchase and consume goods transported over Feral Trade Courier in a restaurant setting. This created a hybrid space which was both a restaurant and an informational exhibition. It included "ingredient transit maps, video, bespoke food packaging and other artefacts from the Feral Trade network. [173]" As one reviewer noted, "By using virtual space to record each trade route, every item you consume in the cafe comes with a narrative. The bland, impersonal act of trade can suddenly come alive with stories, showing us how the items we buy under the normal rules of trade disconnect us from the world in which we live. [174]" While this characterization is in line with Feral Trade's goals, the reviewer went on to comment that

[173] "Feral Trade Café," *HTTP*, accessed May 5, 2011, http://www.http.uk.net/exhibitions/FeralTradeCafe/index.shtml.

[174] William Shaw, "Feral Trade," *RSA Blogs*, accessed June 5, 2009, http://www.artsandecology.rsablogs.org.uk/2009/07/feral_trade.

“[u]northodox supply chains are documented, mapped and displayed on packaging to provoke new conceptions of community and localness […] to include a range of social networks: artworld denizens, family connections, migrant grocers and home farmers. [175]” As we shall see, Rich would reverse that characterization. To her, it is contemporary just-in-time supply chains that are unorthodox. Trading goods over social networks is simply the continuation of social practices that predate globalized shipping.

Couriers Wanted

To become a Feral Trade Courier, one would be asked by Kate Rich or another current or former courier. For example, if Rich knew that I was traveling through London, and needed to deliver goods to the United States, she could ask that I carry a package with me back to my home in Atlanta. From there it could be held until delivered to its destination within the U.S. by someone passing through Atlanta. This trip, and all other trips that a courier or package might take are recorded in the Feral Trade database by the couriers themselves. Looking at the database from their perspective will show us more of the anecdotal information we have discussed, and give us more of a feeling for the way

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[175] Ruth Catlow, Marc Garrett and laurenawright, “Ecologies of Sustenance,” *Furtherfield*, last modified May 15, 2009, accessed May 5, 2011, http://www.furtherfield.org/displayreview.php?review_id=346.

that Feral Trade is informed by the subjective experiences of its couriers.

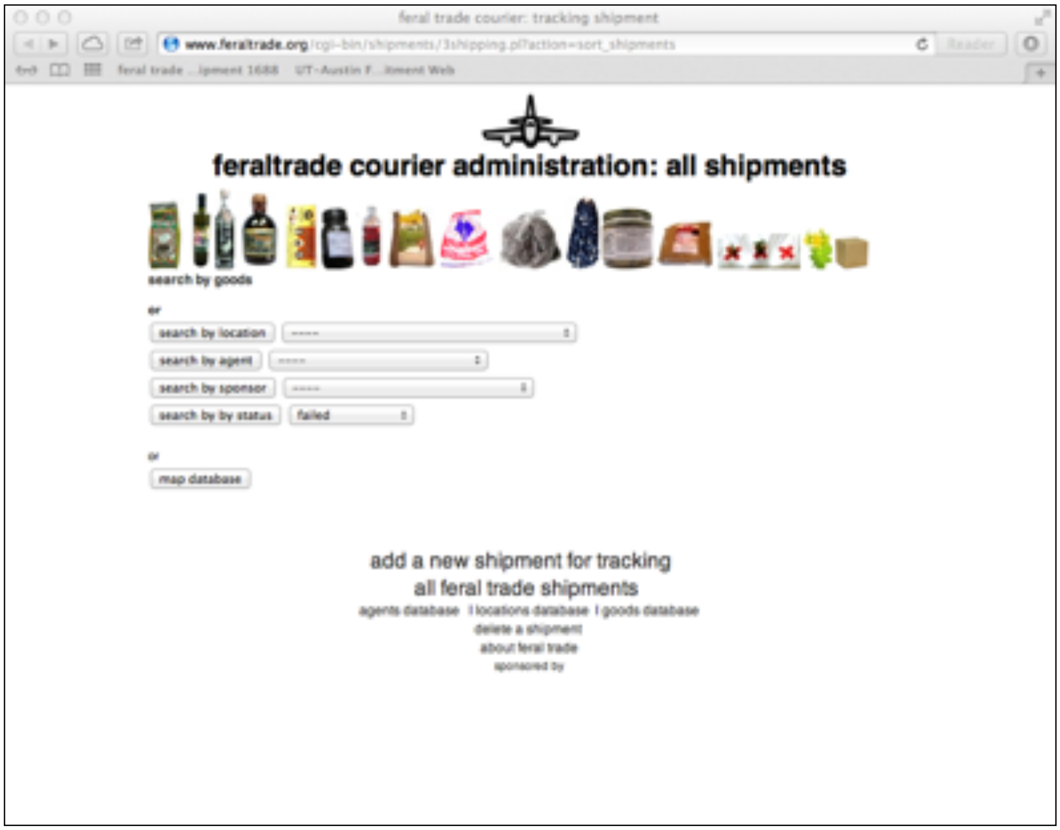

Figure 18. Admin. window of Feral Trade database (http://www.feraltrade.org/cgi-bin/shipments/3shipping.pl?action=sort_shipments, accessed January 19, 2013.)

A Feral Trade courier accesses the password protected Feral Trade database at http://feraltrade.org/trader. After logging in, the courier is presented with a number of options (Figure 18). A row of thumbnail images representing various items shipped by Feral Trade forms a menu across the top of the page which allows a user to search for a particular good. Below that menu are a series of pull-down menus allowing a user to search by location, sponsor, agent, or status. At the time of this writing, the location menu includes

614 entries, beginning with Łódź, Poland, and ending with Zürich Hauptbahnhof, the largest rail terminal in Switzerland. The entries in the location menu vary in kind, some– such as the M1, a highway between London and Leeds which runs for almost 200 miles– are hard to classify as single locations. An exact location along the M1 isn't specified. In other cases, more and less geographically specific locations are listed alongside each other. For example, San Diego precedes San Diego Station in the list. The agent menu includes 354 entries representing both individuals and organizations. The individuals are most often the couriers themselves, and the organizations are those responsible for producing, purchasing, or vending goods. The sponsor menu is less ambiguous. It includes just over a hundred entries that represent entities which were not directly involved in the production, transportation or sale of goods, but which otherwise assisted Feral Trade as a project. The most obvious examples are arts organizations. Finally, the status menu allows a user to select from "awaiting transit," "delivered," and "failed." Failed shipments (of which there are surprisingly few) are described as "(missent, undeliverable, stolen, lost, damaged, crushed, obstructed)[176]." Below all of these menus, users have other options, including adding and deleting shipments.

While logged into the Feral Trade website as a courier we can take a different look at the conversational and anecdotal quality of the descriptions within the Feral Trade database. For example, when accessing the courier report for shipment FER-1688 which consisted of "mixed goods" transported from the European Permaculture Convergence in Kassel, Germany to Eyelevel Gallery in Halifax, Canada, we can read notes left in the

[176] "Shipments," *Feral Trade*, accessed January 19, 2013, http://www.feraltrade.org/cgi-bin/shipments/3shipping.pl.

individual shipping report fields form all couriers. On July 27, 2012, courier Vahida Ramujkic leaves a message for Huang JingYuan, the courier she is supposed to hand off the shipment to. It reads:

> hi jing, i will be heading down to kassel on monday or tuesday. during the day will be between trafo center that is on luther square, close to the hauptbanhof or in the andandand space in turnhale (hauptbanhof). at the moment i cant say exactly how my schedule would look like, but let me know also if you have some ideas how we could arrange meeting. best.[177]

A few days later, on July 31, she reports:

> shipping delivered ! actually i was staying not so far from her hotel. just returned to my village, will send you the rest of the images and info later.[178]

We see the next courier's report begin on the same day. It reads:

> yes, the internet service reminds me of medieval time, but the breakfast is quite modern at least. unfortunately, i can not find a way to pin down where i will be today. Vahida do u think you can drop off at the inter city hotel front desk, still? i will leave on morning of 2nd august.[179]

This same courier checks in again on August 1, and writes:

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[177] Vahida Ramujkic, "Feraltrade courier report for shipment FER-1688," *Feral Trade,* accessed January 19, 2013, http://www.feraltrade.org/cgi-bin/shipments/3shipping.pl?action=courier_form&edit_id=1688.

[178] Ibid.

[179] Huang JingYuan, "Feraltrade courier report for shipment FER-1688," *Feral Trade*, accessed January 19, 2013, http://www.feraltrade.org/cgi-bin/shipments/3shipping.pl?action=courier_form&edit_id=1688.

> hello everyone, so i got the package! thanks for all. but i worry that i won't pass the custom on the "water bottle". theoretically, i don't think they will let any in if they notice. but let us see. i have some babble wraps, that will protect the products.[180]

This conversation, with its complaints about the quality of internet access, explanations of scheduling ambiguities, and worries about packaging and getting items through customs, is quite unlike anything we would expect from the waybill of a mainstream courier. It reveals the degree to which the successful delivery of Feral Trade shipments is contingent upon couriers having the autonomy to make their own arrangements and coordinate with each other in an ad hoc fashion. Rich views this as exemplary of a sort of informal transit which has been obscured by modern logistics. I present these views and analyze them in a later section, but first need to address the development of and maintenance of the Feral Trade database, and Rich's encounters with regulatory agencies–another way that Feral Trade has revealed the social underpinnings of infrastructure.

Infrastructuring and Development

Kate Rich did not begin the Feral Trade project with the intent of developing logistics software–computer applications which facilitate and manage the distribution of goods between producers, distributers, and consumers. It started when she began importing coffee San Ramon from San Pedro Nonualco, El Salvador, a product which is still her main payload. At that time, she was just recording her transactions on scraps of paper and

[180] Ibid.

keeping others in her email. This included information like phone numbers and other contact information and ideal routes to airports. She began to realize that keeping her records in that fashion was ineffective, and would not be manageable in the long term.

As she puts it: “I got to the point where I just couldn’t handle my records. I needed to know what was where and who owed me what and who I owed what.” With that in mind, she began looking for an off-the-shelf software package to address those problems. After looking at spreadsheet applications, content management systems, and other software tailored to the needs of small businesses, she came to the realization that no existing software application would provide her with what she needed to further her project. For example, in terms of databases, she immediately realized that they didn’t have any of the fields that she wanted, fields she describes as “anecdotal, locational, maybe ambiguous, things that kind of shifted between categories.”

Of course, this required her to develop her own software infrastructure. She claims that when she began the Feral Trade project one of her goals as an artist was to get away from computers, that she “just wanted to do something that was kind of manual but it was a system.” After beginning the project, being confronted with the necessity of record keeping and information management, and realizing that there were no appropriate off-the-shelf solutions to her problem, she realized that she was going to have to design and learn to program her own software. She explains: “At that point I realized I had to learn programming to write my own software. [It] felt like, oh God, I’ve got to go back into computers, and I was trying to get away from them. So at the time it just felt like an obstacle, and then, of course, *it became integrated into the project to the point that the ma-*

terial activity and the software activity are inseparable[181] and fit into each other. I started building it with not a very clear idea of what I needed it to do, plus no background in programming. I made a few basic categorization errors at the start that still haunt me. It's very much deliberately a design process that follows form."

This point at which "material and software activity become inseparable," echoes Pipek, Wulf and Star's discussion of "infrastructuring" presented in the first chapter. Echoing Simon, Pipek and Wulf explains that designers have to make decisions–often unknowingly–about what to include and exclude–what is within and what is outside the scope of a particular design project. [182] He notes that this process may result in errors which only become apparent later. If you recall, Pipek and Wulf discussed the difficulty of designers in acknowledging and understanding the routines and patterns of use that support their work. [183] In Rich's case, the Feral Trade database is not just a component of DIY shipping infrastructure; it is her own work infrastructure. When I describe her as DIY, or doing it herself, I am not just referring to Feral Trade's shipping, waybills, etc. She is also creating the system by which she "does" all of those things. She is altering and improving the reflexive relationship between the routines and patterns of her work and the software that supports it.

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[181] emphasis added

[182] Volkmar Pipek and Volker Wulf, "Infrastructuring: Toward an Integrated Perspective on the design and Use of Information Technology," *Journal of the Association of Information Systems* 10, no. 5 (2009): 449.

[183] Ibid.

Database Maintenance and Use

As we have seen, Rich has designed her software so that couriers have the ability to upload information themselves. She describes the software as navigable, with a "reasonably manageable interface," and reminds us that a courier can add reports and pictures, and record points that they passed through en route. However, she reveals "Generally, people don't." She adds, "like all sort of good projects, you've got to do it yourself. I'm very much not into designing system that, like, everyone can do it, because everyone doesn't. Only the most successful design systems do people take on and use themselves. On a small scale, or even on a medium scale, things really only succeed when you do them yourselves. There's a real fallacy in the idea that you design something and everyone will suddenly want to use it. People actually want to do their own thing." When the designer of a system and the designer of the work infrastructure supporting that system are one and the same, the feedback loop that typically exists between design and user is closed. The design choices that a user typically makes in developing their work infrastructure and that a designer typically makes in creating something for that user become coupled and reflexive.

Rich explains: "Counterintuitively, I've found it much easier to get someone to carry 20 bags of coffee from Point A to Point B for me than to get them to upload 5 damn sentences into the database. Getting the information out of people is extremely hard. So with most of the content, I feed the database like a hungry little pet that always needs feeding, because every transaction needs to be recorded." Because of that, she has designed her software with her own needs in mind. She explains that its design is an ongoing iterative process; she is constantly changing it to suit her own needs. For example, she says: “I just did a shipment of 5 kilos of coffee and 14 concentrates to a gallery in Belgium. Five kilos of the coffee plus 7 concentrates are going to Brussels, one place, and another 6 concentrates are going to a different place in Brussels, and 1 concentrate is staying at the museum.” Unfortunately, she adds, “my database doesn’t handle a split shipment very well. I’ve been running into this problem a lot and it’s like, okay, I really need to start coding in split shipments.” So, design changes are implemented as the need arises. Rich is both user and designer, optimizing her own software and workflow, and iterating through possible design changes at the same time she is working through the process of using her database and managing the transactions it facilitates.

Could All Trade Become Feral Trade?

I asked Kate one of the same questions I asked many DIY infrastructure designers. Did she think that the system she had designed could “scale up”? In other words, could existing systems–in this case, systems like DHL, FedEx, and UPS–be replaced by a system or systems like Feral Trade? Her answer was “Definitely, but I don’t think it’s going to happen through people copying my software or taking on my brand or mimicking what I do.” The infrastructure she has developed is something uniquely her own, crucial as a document of the load-bearing capacity of human networks and in exposing the “social” component of systems that are typically veiled behind their technological counterparts. She had two main points to add. First, she feels that Feral Trade exists as a document of existing informal transit systems that predate services like DHL. She believes that these informal transit systems, built on the backs of existing social networks, are still in use today. Second, she believes that social networking software and websites like Facebook promote an inaccurate characterization of actual social networks, which she feels are smaller, tighter, and easier to mobilize. Someone you vaguely remember from high school may be willing to play online games with you over Facebook, but are they willing to carry 20lbs of coffee on their next commercial flight?

Regulatory Frameworks

The Feral Trade Project expanded over time. As it expanded, it came into contact with government regulations, the agencies that enforce them, and their operations. These are further examples of the social component of infrastructure, which includes regulation, the routinization of standards and proscriptions. Kate detailed some of these experiences and the issues they raised.

First, she had to become an importer, and receive an appropriate government ID number. "You get an importer number, a pseudo-TURN number, it's called, from Her Majesty's Custom and Excise." That was simple enough for her. "[P]retty easy […] phone up and ask for one and they give it to you." Next, "you go to the airport. You've got to give them your pseudo-TURN number and show your driver's license and that's it." She describes this step as "low regulation."

Her problems began when she attempted to claim that the first shipment she received at the airport was a personal one. "[T]he Fed agents said, 'Clearly you've got 100 bags of coffee. You can't claim this as personal.'" She found that she had two options to get her shipments through Customs. She could let Customs clear it, or hire a freight agent.

The first option "involves waiting for the Customs people to clear it, and it will take an unknown period of time, in which time your shipment is sitting at the freight agent's office and they charge a daily rate for storage. So it racks up this incredible charge and it takes six to seven days for Customs to clear it." Alternatively, "If you pay the freight agent to clear it, they punch something in their computer and it gets cleared almost instantaneously by Customs and Excise."

Kate shared her feelings on the matter: "It just seems like a scam where it's cheaper for me to pay the freight agent than to pay for the storage. If you go through a freight agent, they just trust that it [the shipment] is what it says on the waybill. They trust that it's coffee from El Salvador and not something else." She noticed that "There's immediate discrimination against the personal importer when compared to the commercial importer who's using a freight agent."

It was cheaper for her to use a freight agent than to pay storage fees. She related the comparative cost at approximately 60 GBP [184] for a freight agent vs. approximately 30 GBP [185] a day for storage. There was not an access problem where Kate, as an independent operator, couldn't contract with a freight agent. She explains "It's really easy to get a freight agent." According to Kate, if a shipper has a freight agent, they almost always clear the shipment without examining it. "It's just mysterious that with the freight agent

[184] Approximately 94 U.S. Dollars on August 9, 2012 at 11 am est.

[185] Approximately 47 U.S. Dollars on August 9, 2012 at 11 am est.

Customs can clear it immediately. If you don't have a freight agent it takes them six days to clear it. They don't actually look at it."

Once, one of her shipments was opened and examined. As she put it, "[B]y the time I got there Customs had actually looked at the shipment. They go into the boxes and knife open a few bags of coffee and then tape it up and there's coffee everywhere. Because it was a tiny shipment of several hundred kilos instead of three shipping containers, I attract more suspicion, so I've been searched a few times. After that search, I looked at the boxes and they just looked a bit light to me, so I said to the freight guys – they had fork-lifts and stuff – 'Can you just weigh these boxes? I just want to be sure that it's the same weight as on the waybill, so I know that Customs didn't nick any of the coffee.' And they just laughed and said, 'We can make the waybill say anything we like.'" As she explained, a waybill is intended as an "absolute document" which is signed off on by the sending party and freight agent. It is supposed to describe the contents, their weight and their point of origin. The customs workers were basically telling Kate that the allegedly absolute document which was supposed to accurately record import data for the government was filled in arbitrarily.

Kate details a second experience of estrangement with regulators. One weekend she called the freight agent regarding a form that she had been faxed. The form needed to be signed by the freight agent. According to Kate the freight agent said, "I won't be here. Just write my signature."

"What?" Kate asked.

"Just scribble my signature on it and show them. It will be fine." The freight agent said.

"She didn't know me at all," Kate explained. "Checks and balances at the border are much looser than you'd be led to believe by following the legitimate system."

Eventually, after running the Feral Trade courier project for about seven years, Kate was raided by Trading Standards, the U.K.'s governmental agency enforcing consumer legislation. According to Kate "they're the most powerful government body. They're the only people who can enter your home without a warrant, unlike the police, so they've got more power than the police." They went to an old address of Kate's that was listed on her website "and bashed on the door." Kate says a friend answered the door and informed them that Kate no longer lived there. Next, they went to the cinema where Kate works, but no one was there. In looking for Kate, they had left someone a mobile phone number so she called them to get to the bottom of things. "They'd given their mobile number so I phoned them and said, 'If you want to meet me, why don't you just get in contact with me instead of bashing on the doors of places where I might be?' They kind of admitted that they were trying to spring a raid on me. So we met up. I looked at my server logs and they'd spent three to four hours on the website and gone to just about every page."

Kate continues "There were two of them. They were all over the place and they were also very sharp. They did a kind of good cop-bad cop thing, trick questions. They understood it was an art project. I understood that that wasn't any excuse for breaking rules. They interviewed me for two hours, asking questions like, 'The sweets from Iran on your website, they seem very brightly colored.' And I said, 'Well, I used Photoshop. I tried to make the photo look good.' […] They were questioning various ingredients and they thought there were illegal food colorings in the sweets because of the Photoshop."

Next, "[t]hey picked up that in the logo section of my website I have the logos of all the sponsors that deliberately or inadvertently helped a shipment take place. When I was in Tijuana I went across the border to […] a Starbucks to get the coffee ground and the kind employee ground the coffee for me. So, I have their logo on the website and [trading standards] said that they would shut me down if I didn't take that logo off." Her website also displayed the logo of the U.S. Peace Corps. According to Kate, they had "been an enormous help locating and securing the coffee supply. [Trading standards] told me I had to take that logo off too, so I did."

Kate feels that "for research purposes" it was a great experience. This sort of sentiment doesn't seem strange coming from a DIY infrastructure designer. Recall that very few of these projects are conceived of as businesses, and that when they are they are often primarily concerned with using that business as a means to an end other than profit. DIY is typically the domain of non-experts who are motivated by curiosity and altruism more than profit. Feral Trade is motivated by such curiosity, and primarily concerned with revealing the social element of transportation infrastructure. These encounters with the enforcers of regulation would likely be considered problematic by the standards of others. To Kate they are a success, because they reveal social relationships which constitute infrastructure and would otherwise go unseen.

After a while, she continues "They lost interest […] because they couldn't find anything to really get me on. Now, they've approved my business, basically, because they haven't done anything to shut me down. But the swinging point for them – and this is why I'm telling this long story – is except for the coffee, all of the stuff that I handle I do bring in as personal imports. For example, I came back from Iran with 40 or 50 boxes of sweets, but it wasn't commercial and every box was preallocated to someone. I told people before I was going, 'I can only carry a certain amount. Put your orders in now,' so every box had the name of the recipient on it. What I'm doing is scaling up that thing where you travel somewhere and you bring back a bottle of the local whatever for your friend. I'm doing that with a large group of friends that I couldn't give the things to so I need to sell them, but it's really on the cusp between what's considered commercial importing and what I consider as personal use."

Kate sought out more answers about the boundary between personal and commercial imports: "I'd spoken to quite a lot of authorities by then, and I've forgotten the name of the agency I ended up talking to eventually but they're really definitive on this question. I didn't get it in writing, which is a real shame, but I got it vocally, spoken, on the phone. The woman said, 'We don't actually have any regulations that handle the conversion of a personal import into a public product.' For example, I've brought in sweets and teas in my personal importing that I've ended up serving to the public as part of an event. So they say that there is actually no governance that they have for that transaction. This is a kind of tiny, blurry territory that I'm operating on, and it's a territory between jurisdictions […] It's like I found some kind of island that's small, very blurry. There's no regulations forbidding or even alluding to what I'm doing. So that was a very exciting moment."

Valorized Monopolies

Kate's experiences with these regulator agents reminded me of my interview sessions with other DIY infrastructure designers, in which some described feeling that existing infrastructure writes its own narrative and that its narrative goes unquestioned. I asked Kate Rich her thoughts on the matter. Did anyone ask her "What are you doing? Why not just use FedEx?" and she replied "Interestingly, no one has ever said that to me. People get it immediately. 'I could always put things in the mail, right?' Everyone enjoys the idea so much, instinctively, that actually no one has ever said that to me, and I haven't thought of it before, so that's a good test of the fact that these narratives aren't actually completely locked in." Kate also shared a couple of thoughts on transportation services as infrastructure.

First, location and access of a population to these services creates interesting incongruities. "In America, DHL and FedEx, these guys are monopolies. They're competing for the same trade so they've followed each other's design. In Bangladesh these things [DHL and FedEx] aren't monopolies. They're too expensive. DHL exists but it's inaccessible to people. There's another dominant system of deliveries there. These things aren't inevitable. A monopoly is not natural. It's being encouraged by certain legislation and economic business climate and things that have been allowed by regulation. What DHL has replaced is all of the ad hoc, smaller scale, smaller business deliveries."

Second, although their ubiquity may make them seem heavily centrally structured, the structure of some of these transportation systems may in some ways be ad hoc. "Interestingly, when you actually look at DHL, it barely exists except as a financial entity, because whoever turns up at your door, it's just some guy in a van. You ask them something and they don't know. They're just the driver. They're almost, actually, a freelancer who drives. They're not exactly a company employee. They're not part of an endeavor." Here we can detect, along with a hint of a sense of superiority, one of the essential characteristics of DIY. Rich's description of DHL's drivers as "not part of an endeavor" contrasts the volunteer and typically non-commercial stance of DIY with that of the corporation. DIY infrastructure's designers and users are part of an endeavor.

Informal Transit

According to Kate, the type of shipping that she is promoting and performing is "completely prevalent anyway." She references a quote that she is unable to source. Its author, she claims, a sociologist, argued that the majority of freight in the United States was not moved by DHL or FedEx. "The biggest freight agent is your friends, saying, 'Oh, can you just drop this off at the post office for me?' or 'Can you take that to Mom?' You know, these little informal trips." She gives the example of freight in Bangladesh being handled through an unbranded and "completely impenetrable system" where you go into a local courier's shop to interface with a system that has several small agents traveling at any time.

She continues, "the information gets transmitted–where it's going to go, and it goes point to point. It's a very interesting, semi-informal system." She also gave the example of people in Iran transporting goods via public intercity buses, without having to accompany their packages. “You just put your cargo in the luggage system and pay and it goes on the coach” she explains. She argues that these sorts of arrangements used to be more prevalent in the West, before the host of security concerns that arose from weaponized packages. Of course, without an existing and robust freight infrastructure, weaponized packages would be far less dangerous. They could not, for example, explode while in transit, destroying airplanes, trucks, or locomotives, and triggering a variety of cascading effects.

“In England, you used to be able to do that with the trains. There was actually a service where you could put your bag on the train on its own, and pay, and someone picked it up at the other end. All of that stuff has been blasted away by various security control agendas. But these things are actually alive in other countries.” For example, members of the Iranian diaspora “leave Tehran airport with massive bags, which are all full of sweets and specific items of clothing and spices and whatever they take to their families living outside Iran. There are many, many examples of informal transit that still exist.” Because of these types of informal transit systems, Kate does not feel that she is doing anything new in creating and maintaining Feral Trade as both an artwork and a service. “I don’t think I’m inventing anything,” she says. “I’m just recording it in a novel way.” Through her database and other documentation and through the management of Feral Trade and the software and relationships that support it, Kate is revealing and recording the social component of infrastructure. Her experiences doing so led her to a second observation.

The Scale of Social Networks

Kate's second point of interest is the size of social networks. According to Kate, "Social networks do not scale. [T]his is the fallacy that Facebook promotes, the idea that you can just have this kind of digital multiple of friends. [S]ociological research shows that you have a finite number of friends that you can handle at any one time. Several years before Facebook – […] I started in 2003 – my intention […] was to test the load-bearing capacity of social networks, […] could you use social networks to carry freight? What my database reports, the maps and the list of transactions, [is] not a speculative relationship between people. It's an actual relationship because someone actually traveled that route with an item and delivered it to the end destination."

"[T]hese are real, existing, proven relationships between individuals and also between individuals and institutions, because there are a lot of small-scale art organizations and bookshops and cinemas and universities and other entities that are involved as delivery points and depots. I am trying to show […] real social networks that don't scale, they're not mechanically or digitally reproducible, and the only reason to have a digitally reproducible social network, […] is so that you can mine them for data, which is the direction that […] Google and Facebook are moving into. So these [Feral Trade Courier's] are social networks that are not harvestable or mineable."

Kate describes "[t]he Feral Trade database [as] an extended self-portrait." "It's me," she explains "the social networks around me, the extended social networks. I don't know everyone who has been a courier or a supplier or receiver in my network. I know maybe half of them. Others are friends of friends, parents of friends, employers of friends, but it is a genuine, three-hop social network that changes but doesn't scale up. However," she points out "everyone has one." Kate sums up this aspect of Feral Trade Courier as an attempt to "represent a model of trade that's underrepresented online and in popular conversation, because people have got very lulled by the ubiquity of DHL and FedEx, and that is the dominant narrative of distribution." She adds "On a technical level, I've got the data."

In terms of the reach of Feral Trade Courier, the distance that Kate is able to use her social network to move physical goods, she explains "I've been running this for eight years. I now feel pretty confident I can get something from anywhere to anywhere. It's like 'not-in-time delivery.' It can take quite a while; things get stuck. But I'm very confident I could get something to anywhere in the U.K. Just drop it off in London and everyone goes to London so I can get something anywhere in the U.K. I can get to most places in Belgium. France is trickier for me. But you start to get a confidence. I got hot chocolate from Mexico to Newcastle in time via, in turned out, Denmark and Berlin, which was just random. These routes do work. It's kind of on the basis of this degrees of separation thing, but again, [...] it's the load-bearing element of it that has to come through. So I would be completely confident that this could completely displace commercial shipping, but not through printing out the template and everyone does it. More as a narrative, as an understanding of how infrastructure can be produced." In spite of the fact that this is often the last thing we think of when investigating infrastructure, it is the key lesson we want to take away from Feral Trade: The production of infrastructure is heavily contingent on understanding and anticipating human social interaction. This is especially important to DIY infrastructure projects, which rely on volunteers and groups with affiliated interests.

While Feral Trade reveals the contingency of infrastructure upon the social, that contingency is just as important in the next two case studies. In the next chapter, I discuss two projects, Village Telco and Fluid Nexus, which use such local ties to create a new sort of telecommunication infrastructure. In the following chapter, I present Cloacina, a DIY sanitation infrastructure project that began as an attempt to replace the physical network of pipes in a sewer system by implementing the same sort of social-network-based logistics that Feral Trade demonstrates.

7. DIY TELECOMMUNICATIONS

This chapter details and analyzes a number of DIY infrastructure projects within the domain of telecommunications. Unlike other sections, which focus on individual projects in depth, here I conduct a broader analysis of two separate projects: Village Telco and Fluid Nexus. This allows us to compare them, noting differences in motivation and implementation. As I noted previously, DIY infrastructure projects can occupy a void between the interests of infrastructure's owners and operators and its users, and this can be part of a response to the alleged irreversibility of large-scale public works and their consequences. As such, DIY infrastructure projects can approach issues such as the resilience and criticality of infrastructure with a degree of freedom that the operators of public works cannot. With that in mind, I begin by defining "resilience" and providing an overview of resilience and critical infrastructure.

Recently, catastrophic events such as Hurricanes Katrina and Sandy and other portents of larger-scale infrastructural failure have increased the visibility of critical infrastructure in popular and scholarly literature. Resilience, the ability of a system to withstand disruption or return to operation after a shock, has been offered as a solution to this problem. Unfortunately however, resilience is often inconsistently defined in crisis response and critical infrastructure literature. So, to begin, I provide a definition of resilience through a synthetic analysis of ecological theories and adaptive ecosystem management strategies. While these areas of research may seem to lie outside of the purview of the study of infrastructure, they provide us with the necessary concepts to evaluate the ways that DIY infrastructure projects interact with established infrastructures and their resilience. As we will see in the case studies of Village Telco and Fluid Nexus that follow, resilience becomes a design strategy as new telecommunication infrastructures are designed to add redundancy to an existing ecosystem of technologies. Thus, they offer proof of the concept of ecological resilience. Ecological resilience provides us with a new conceptual model, while DIY infrastructure projects illustrate new possibilities. The affordances of digital media are then utilized to reconfigure the relationship between participants in communication networks. These projects occupy a void between institutional and market responsibilities.

Two Concepts of Resilience

Put very simply, resilience is the ability to withstand disruption through adaptability. A policy of resilience can complement, and sometimes be more efficient than, attempts to anticipate and deter systemic shocks. For example, it may be a better solution to ensure that infrastructural systems will not fail, or will fail only briefly because of a disaster or a terrorist attack, than to attempt to anticipate and deter all conceivable disruptions. However, resilience is often ignored, or discussed in terms which are too simple. For example, the book *Resilient Cities: Responding to Peak Oil and Climate Change*, only explains that “Resilience is the capacity of a system to absorb disturbance but still retain its basic function.” [186]

Many of these superficial attempts to define resilience are at least noteworthy because they recognize the fragility of a number of global systems and show that traditional command-and-control management and just-in-time supply chains may possess significant vulnerabilities. However, they neglect to include a discussion of the amount of a disruption that systems can withstand and why. Instead, much popular and scholarly literature focuses on worst case scenarios: what happens if and when systems fail, using these scenarios to rationalize everything from organizational restructuring and policy change to stockpiling weapons.

In ecological literature however, two specific types of resilience are defined. The more traditional type measures resilience as the ability to withstand the disturbance of, and return to, a single point of equilibrium. This is referred to as equilibrium or engineering resilience. The second type, referred to as ecosystem resilience, emphasizes “conditions far from any equilibrium in which instabilities can flip a system into another regime of behavior-to another stability domain.” [187] This type of resilience is measured by the severity of a shock that can be “absorbed or accommodated before the system changes its structure by changing the variables and processes that control system behavior.” [188] Put another way, ecosystems have multiple points of equilibrium: “Ecosystems do not have

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[186] Peter Newman, Timothy Beatley, and Heather Boyer, *Resilient Cities: Responding to Peak Oil and Climate Change* (Washington, D.C.: Island Press, 2009).

[187] C. S. Holling, “Engineering Resilience versus Ecological Resilience,” *in Engineering Within Ecological Constraints*, ed. Peter C. Schulze (Washington, D.C.: National Academies Press, 1996), 31-44.

[188] Ibid.

single equilibria with functions controlled to remain near them. Rather, destabilizing forces far from equilibria, multiple equilibria, and disappearance of equilibria define functionally different states, and movement between states maintains structure and diversity." [189] C.S. Holling, one of the fathers of ecological economics, adds that engineering, the first type of resilience, "focuses on efficiency, constancy, and predictability-attributes at the core of command-and-control desires for fail-safe design," while the second "focuses on persistence, change, and unpredictability."

One way to visualize these two examples is to consider different material properties. A rubber band or piece of elastic can withstand a certain amount of force. This force will deform it, but will not break it unless it exceeds a certain threshold. Once this force stops being applied, the rubber will return to its original form. This is an example of equilibrium or engineering resilience.

As an illustration of ecosystem resilience, consider a ball at rest at the bottom of a curved surface, such as a basin or valley. Imagine an adjacent valley, separated from the first by a mountain. If a sufficient amount of force is applied to the ball, it may cross the peak of this mountain–the highest point in this diagram– into the adjacent valley. If this force stops being applied before this happens, the ball will roll back to its original position of rest at bottom of the valley. The two lowest points in this diagram, the bottoms of the valleys, represent the multiple equilibria of a resilient ecosystem. The highest point, or mountain's peak, is the amount of a disturbance the system can withstand before it

[189] Ibid.

changes states. In an example in which the two valleys have different depths, there will be different quantities of disturbance withstood before a state change.

Perhaps even more significant than the functional differences between these two types of resilience are the differences in our reactions to them. Ecosystem resilience is a more abstract concept. In considering it, one is forced outside of the comfortable confines of simple “X causes Y” causality, closed systems and deterministic behavior, and into the more complicated space of feedback and events triggering events. This space is far more difficult to define, leading Bryan Norton, a scholar of adaptive ecosystem management, to the conclusion that “the ‘problem’ of uncertainty is really a grab bag of more or less related problems, all resulting from the fact that our finite knowledge will always fall short of any idea of ‘full’ knowledge upon which to base everyday decisions. Uncertainty, in this sense, is just a general label for all of the failure of our scientific models.” This type of thinking is not simply foreign to traditional ecosystem or infrastructure management; it may be foreign to the way people think about events. Holling puts this quite aptly, addressing both classical economics and mechanics in the process: “If there is more than one equilibrium, in which direction should the finger on the invisible hand of Adam Smith point? If there is more than one objective function, where does the engineer search for optimal designs?” In short, the consideration of multiple equilibria forces us outside of the comfort of our assumptions of cause and effect.

The roots of engineering or equilibrium resilience “draw predominantly from traditions of deductive mathematical theory where simplified, untouched ecological systems are imagined.” Holling argues that the theory “makes the mathematics more tractable,” and that it can “accommodate the engineer’s goal to develop optimal designs.” He cautions, however, that “There is an implicit assumption of global stability [...] that only one equilibrium steady state exists,” and that “if other operating states exist, they should be avoided by applying safeguards.” [190] This assumption of global stability can have negative consequences.

This reveals an important result of ignoring the distinction between these two types of resilience. As Bergen, Bolton, and Fridley argue, “management policies that force ecosystems to function in a state of engineering resilience lead to a loss of ecological resilience.” As an example, they discuss “systems managed to produce a consistent, high yield of a single variable (such as timber or fish),” and that because of this process of management they “lose the functional and structural diversity required to remain ecologically resilient.” [191] Stated differently, there is danger in the misapplication of these models. Adopting the wrong model can damage the system.

As Holling and his co-author, conservation biologist G.K. Meffe state, thinking through the results of the ecosystem and engineering models can “draw attention to the paradoxes between constancy and change or between predictability and unpredictability. [192]” As we see here, the model of ecosystem resilience can help us out of a difficult–almost clichéd–position: being aware that “traditional” views of cause and effect and the

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[190] Bryan Norton, *Sustainability: A Philosophy of Adaptive Ecosystem Management* (Chicago: The University of Chicago Press, 2005).

[191] Scott D. Bergen, Susan M. Bolton, and James L Fridley, “Design principles for ecological engineering,” *Ecological Engineering* 18, no. 2 (2001): 201–210.

[192] C. S. Holling and Gary K. Meffe, “Command and Control and the Pathology of Natural Resource Management,” *Conservation Biology* 10, no. 2 (1996): 328-337.

way that they inform models and practices of management are prone to error because they are too simple to explain the dynamic and chaotic behavior of the real world, but being forced to fall back on those same models and practices because of a lack of alternatives. While a consideration of multiple equilibria may require a slightly awkward or painful deviation from standard operating procedure, it is superior to the quixotic application of disproven models. In contrast to this repetition of ineffective solutions, DIY infrastructure projects, being detached from the status quo, can explore an alternative space of design solutions that existing interests do not.

The Status Quo

Let's compare ecological and engineering resilience with the status quo, a situation of infrastructural fragility in which systems may be highly optimized. This optimization may decrease their resilience, and resilience may only be considered insofar as it is synonymous with a reduction in liability. The status quo can be described as a strategy of anticipation in which resources are allocated to averting disruption. This strategy is problematic because of the ubiquity of fragile infrastructural components.

Take, for example, a natural gas pipeline. It may run through several states and a variety of types of terrain. Guarding such a structure against accidental disruptions would require a significant investment in manpower. [193] Furthermore, there is always the possibility of deliberate disruption–military attacks on critical infrastructure itself. Martin Cow-

[193] See Robb's summarization of the design flaws of highly optimized systems here: http://globalguerrillas.typepad.com/globalguerrillas/2004/05/design_flaws_wh.html.

ard, author of *Urbicide: The Politics of Urban Destruction*, argues that both the "shock and awe" precision bombing tactics and "effects-based operations" of the United States invasions of Iraq and Al-Qaeda's attacks on the World Trade Center and the train systems of London and Madrid show us that the "heart of the posited relationship between the city and warfare is the propensity for forms of organized violence to target critical infrastructure." [194] Coward reminds us that historically, "the city became a target precisely because it hosted the technical systems that were necessary for the enemy to continue to wage war. Undermining an enemy's capacity to deliver communications, intelligence, personnel, munitions and other supplies to the battlefield became an important tactical means for realizing strategic aims in modern warfare. [195]" In line with Edwards' thinking on infrastructure and modernity, Coward argues that "critical infrastructure can be said to comprise that which is constitutive of, not simply located in proximity to, contemporary metropolitan urbanity. This is reinforced by the manner in which targeting critical infrastructure seeks to disrupt urban life (through generating fear, impeding circulation, and imposing unacceptable economic and human costs). Targeting critical infrastructure in order to disrupt urbanity thus comprises a historically specific form of violence. [196]"

Returning to the example of guarding a natural gas pipeline, we'll have to ask new questions about the possibility of deliberate disruption. What additional resources and what types of resources would need to be allocated to protect the pipeline? A fence?

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[194] Martin Coward, "Network-Centric Violence, Critical Infrastructure and the Urbanization of Security," *Security Dialogue* 40, nos. 4-5 (2009): 399-418.

[195] Ibid.

[196] Ibid.

Armed guards? Surveillance cameras? Of course, if natural gas pipelines have been targets in the past, we'll have to account for the fact that the status quo also involves security theatre,[197] the state's collective expression of response to attacks which have already happened, concentrating defense on the site of the last attack regardless of the likelihood that it will become the site of the next.

Lance Gunderson, a systems ecologist, describes the status quo as a situation in which "Resource managers constantly grapple (explicitly and implicitly) with uncertainty. One approach is to assume most uncertainty away [...] Another approach is to seek spurious certitude, that is, to break the problem or issue into trivial questions spawning answers and policy actions that are unambiguously "correct," but, in the end, are either irrelevant or pathologic." This involves replacing "the uncertainty of resource issues with the certainty of a process, whether that process is a legal vehicle–such as a new policy, regulation, or lawsuit–or a new institution–such as a technical oversight committee or science advisory committee."[198]

Holling and Meffe extend this diagnosis of "irrelevant or pathologic" to other institutions, claiming: "bureaucracies are an exercise in variance reduction through regulation and control; their purpose is elimination of extreme behavior through regulation to promote conformity to a specific set of standards, which to some degree is certainly desir-

[197] See Bruce Schneier's *Minneapolis Star-Tribune* op-ed of August 13, 2006, reprinted here: http://www.schneier.com/blog/archives/2006/08/terrorism_secur.html, or Jeffery Goldberg's November 2008 article for *The Atlantic Monthly*, here: http://www.theatlantic.com/doc/200811/airport-security.

[198] Lance Gunderson, "Resilience, Flexibility and Adaptive Management - Antidotes for Spurious Certitude?" *Conservation Ecology* 3, no.1 (1999): 7.

able in a civilized society.[199] But deeply entrenched bureaucracies are characteristically susceptible (or un-resilient) to new challenges because the system discourages innovation or other behavioral variance. This is clearly evidenced by merely presenting a unique situation to a clerk who has been narrowly trained in a highly standardized bureaucracy and watching the incredulous reply or by the typically negative response to and occasional punishment of a government employee who offers an alternative perspective to the standard operating procedure."[200] A critical facet of DIY infrastructure projects is their drive to address the pathology of the status quo.

The conflict between engineering and ecological resilience recalls Simon's conception of design as a process of optimization and search and the difficulties with that conception presented by subsequent design scholars. We can see engineering resilience, in which there is a single point of equilibrium, as corresponding to Simon's model. We can see ecological resilience, in which a system may possess multiple points of equilibrium and in which optimization may run counter to resilience, with Horst and Rittel's conception of wicked problems, as well as being broadly connected to design for sustainability. In this way, the conflict between optimization and resilience embodies the conflict between these conceptions of design.

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[199] This corresponds to the role of conformity enforcement, one of the five roles in complex adaptive systems described by Howard Bloom in his book *Global Brain: The Evolution of Mass Mind*, New York: Wiley, 2001.

[200] C. S. Holling and Gary K. Meffe, "Command and Control and the Pathology of Natural Resource Management," *Conservation Biology* 10, no. 2 (1996): 328-337.

Optimization vs. Resilience

There is a conflict between optimization and resilience. Egan argues that "creating reliability [...] in complex, tightly coupled systems is difficult," and that "the hope of doing so grows increasingly distant as technological systems grow larger and more complex." [201] In some cases, deregulation may increase this complexity. *Critical Foundations: Protecting America's Infrastructures*, the 1997 Report of the President's Commission on Critical Infrastructure Protection, raises this possibility: "The unbundling of local networks mandated by the Telecommunications Act of 1996 has the potential to create millions of new interconnections without any significant increase in the size or redundancy of network plants. Unbundling will be implemented at a time of rapid and large scale change in network technologies. The interaction of complexity and new technologies will almost certainly expand the universe of ways in which system failure can occur, and, unlike natural disasters, there is no assurance that such failures will be localized." [202]

Furthermore, owners may optimize infrastructural systems to increase profits even when such optimization may lessen resilience. Schulman and Roe believe that efforts to optimize the functioning of large technical systems may actually make them less resilient: "We are asking how to harden them against hostile assault from external sources or how to decentralize them in order to suffer less damage from successful assaults. At the same time, we are not asking how ongoing efforts to increase their efficiency or optimize their

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[201] Matthew Jude Egan, "Anticipating Future Vulnerability: Defining Characteristics of Increasingly Critical Infrastructure-like Systems," *Journal of Contingencies and Crisis Management* 15, no. 1 (2007): 4-17.

[202] Paul R Schulman and Emery Roe, "Designing Infrastructures: Dilemmas of Design and the Reliability of Critical Infrastructures," *Journal of Contingencies and Crisis Management* 15, no. 1 (2007): 42-49.

performance might be undermining their reliability from within." So, resilience may run counter to optimization, and highly optimized systems may be less tolerant – in part because they may be less forgiving and more difficult to repair.

This is similar to a critique of oversimplification in ecological literature. Holling argues that "reducing the variability of critical variables within ecosystems inevitably leads to reduced resilience and increased vulnerability." [203] The reduction of variability is also a goal of engineered optimization which can have serious effects on system resilience. Consider the following, in which Holling and Meffe discuss the effects of such a reduction in variability by command-and-control activities, going so far as to include both natural and man-made disturbances to the system: "a system in which natural levels of variation have been reduced through command-and-control activities will be less resilient than an unaltered system when subsequently faced with external perturbations, either of a natural (storms, fires, floods) or human-induced (social or institutional) origin." [204] The authors have the foresight to recognize this as a more general attribute of multiple systems: "this principle applies beyond ecosystems and is particularly relevant at the intersection of ecological, social, and economic systems." Carlson and Doyle, two physicists researching complex systems behavior, extend this understanding of the relationship between complexity and robustness to the realm of engineering: "one of the most important properties of complex biological and engineering systems that has no counterpart in physics, [is] that complexity is driven by profound tradeoffs in robustness and uncertainty." It

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[203] C. S. Holling, "Engineering Resilience versus Ecological Resilience," in *Engineering Within Ecological Constraints*, ed. Peter C. Schulze (Washington, D.C.: National Academies Press, 1996), 31-44.

[204] C. S. Holling and Gary K. Meffe, "Command and Control and the Pathology of Natural Resource Management," *Conservation Biology* 10, no. 2 (1996): 328-337.

is from these assertions of the wider application of this relationship that I consider DIY infrastructure.

DIY Infrastructure, Resilience and Adaptive Management

We can see DIY infrastructure as an alternative to the status quo, and as adopting of a model of ecosystem resilience. Instead of shocks to an infrastructural system causing a fracture of critical failure, significant shocks would now force the infrastructure in question into a secondary state or point of equilibrium. Assuming its primary state displays more desirable qualities, a recovery could be seen as a shift back to that primary state. Put differently, in considering a hypothetical critical infrastructural system designed according to ecosystem resilience criteria, we see that the nature of disruption would be changed. As Sedano explains, "instead of on/off we would see a switch to a redundant system. Distributed systems have lower reserve margins.[205]"

In terms of application, this could require the addition of new service providers to the market and an investment in redundant components. Sedano argues that the addition of new providers "may require significant infrastructure investment pressure from government, as increased competition may not be in the interests of current service providers, but government is the builder of last resort."[206] Of course, there is another option that Sedano does not consider: the DIY response. For example, we have already discussed

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[205] Richard P. Sedano, *Dimensions of reliability: A paper on electric system reliability for elected officials*, The Electric Industry Restructuring Series, National Council on Competition and the Electric Industry, 2001, http://www.naruc.org/Publications/relforleg5.pdf.

[206] Ibid.

Cloacina as a potential new non-governmental service provider, and we can say the same of Fluid Nexus and Village Telco, the two DIY Telecommunication projects discussed in this chapter.

One can view DIY infrastructure as embodying an alternative of adaptive management. While adaptive management stands in stark contrast to the status quo it should not be viewed as being exclusive to either engineering or ecosystem resilience, as it can complement both. According to the U.S. Department of the Interior, "Adaptive management promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. [...] Adaptive management also recognizes the importance of natural variability in contributing to ecological resilience and productivity. It is not a 'trial and error' process, but rather emphasizes learning while doing." Adaptive management would leave repair and maintenance workers less encumbered by what Gunderson calls the "spurious certitude" forced upon them. Graham and Thrift remind us of the significance of repair and maintenance, arguing that they are not just significant in catastrophic situations: since they are ongoing, then breakdown is significant; it is part of the process by which societies learn, forming "a continuous feedback loop of experimentation," trying to stave off entropy. Repair and maintenance "illustrate the importance of human labour and ingenuity. [207]" So, a shift to adaptive management may be anathema to some existing cultures of management, but their adaptation and ingenuity may surface as a de facto operating procedure in spite of managerial constraints.

[207] Stephen Graham and Nigel Thrift, "Out of Order: Understanding Repair and Maintenance," *Theory, Culture & Society* 24, no. 3 (2007): 1-25, DOI: 10.1177/0263276407075954.

Adaptive management favors the local knowledge of the indoctrinated, a trait it shares with DIY infrastructure. Recall Star's attributes of infrastructure discussed earlier. To her statement that infrastructure is "learned as a part of membership," she adds "strangers and outsiders encounter infrastructure as a target object to be learned about. New participants acquire a naturalized familiarity with its objects as they become members."[208] Graham and Thrift's arguments affirm that those engaged in the repair and maintenance of infrastructure are among the indoctrinated, but it is Lee's assessment of adaptive management which brings us back again from ecosystem to infrastructure: "Those who operate the human infrastructures of harvest–farmers, ranchers, dam operators, loggers, fishers–are usually those who know most, in a day to day sense, about the condition of the ecosystem."

We can see a similar sentiment in some other DIY infrastructure projects. Cloacina's designers scoff at the idea that their designs could be applied outside of their local area. To them, this just belies poor problem formation. Feral Trade Courier is an attempt to open the black box of infrastructure, exposing the human infrastructure of transport. To many DIY infrastructure designers, the development of their own working conventions and routines is seen as just as essential and vexing as the development of artifacts and systems. In the case of Feral Trade, documenting these conventions is understood as on par with documenting other aspects of transportation infrastructure such as routes and times.

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[208] Susan Leigh Star, "The Ethnography of Infrastructure," *American Behavioral Scientist* 43, no. 3 (1999): 377-391.

This ties in to Star's ideas of articulation work and routine. She discusses the seemingly irrational disruption of routine by minor alterations. Her example stems from a discussion of an attempted alteration of a worker's routine (in this case changing their interaction with the computer), claiming that to the workers she was observing, "an extra keyboard stroke might as well be an extra 10 pushups." To explain this, she argues that two coupled processes are occurring simultaneously, one that involves "keystrokes and functionality," while the other is a "process of assemblage," or "articulation work." She defines this articulation work as the "complex weaving together of desktop resources, organizational routines, running memory of complicated task queues" which are "performed invisibly by the user." [209]

DIY infrastructure acknowledges the fact that people are adaptable and are already adapting. Outsiders may not consider the fact that both DIY infrastructure designers and many everyday users of infrastructure are involved with an invisible and ongoing process of repair, maintenance, rigging, and hacking. As Kate Rich's work with Feral Trade has exposed, just-in-time delivery systems may be more resilient than we anticipate because of this human element, while on the other hand the "human factor" may make systems even more prone to disruption because a seemingly trivial event can disrupt articulation work and the invisible mastery of task queues.

Graham and Thrift argue that the increasing complexity of infrastructure demands increasing amounts of maintenance, that the increased connectivity of infrastructural systems "makes it harder to isolate the object of repair," asking "what is being repaired? Is it

[209] Ibid.

the thing itself, or the negotiated order that surrounds it, or some 'larger' entity?" Though they are discussing infrastructure, their comments echo the tenets of adaptive ecosystem management. In contrast to the space of experimentation, they explain that "command-and-control management can lead to short-term economic returns, but it also increases the vulnerability of ecosystems to perturbations that otherwise could be absorbed. Any move toward truly sustainable human endeavors must incorporate this principle or it cannot succeed."[210] Thus, increasing infrastructural complexity and the resultant difficulty in isolating a single point of repair may solicit a harmful managerial response. Gunderson states this explicitly: "Not only do ecosystems become less resilient when they are managed with the goal of achieving constancy of production, but the management agencies, in their drive for efficiency, also become more myopic, the relevant industries become more dependent and static, and the public loses trust.[211]" We see similar comments from Schulman and Roe, who argue that the resilience of infrastructural systems lies "not primarily in the design ... but rather in their management.[212]" Like Graham and Thrift, they view humans as important parts of technical systems.

Let's turn to some new case studies from the domain of telecommunication. They can be seen as populating the void between institutional and market responsibilities we have just discussed. They also offer proof of the concept of ecological resilience: they are de-

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[210] C. S. Holling and Gary K. Meffe, "Command and Control and the Pathology of Natural Resource Management," *Conservation Biology* 10, no. 2 (1996): 328-337.

[211] Lance Gunderson, "Resilience, Flexibility and Adaptive Management - Antidotes for Spurious Certitude?" *Conservation Ecology* 3, no.1 (1999): 7.

[212] Paul R Schulman and Emery Roe, "Designing Infrastructures: Dilemmas of Design and the Reliability of Critical Infrastructures," *Journal of Contingencies and Crisis Management* 15, no. 1 (2007): 42-49.

signed as redundant communication systems which will complement–not replace–existing systems.

Village Telco

The first is Village Telco, which provides a simple platform for creating local telephone service and is built around open source, standards-based wireless networking technology. Village Telco's website offers this description: Village Telco is "[a]n initiative to build low-cost community telephone network hardware and software that can be set up in minutes anywhere in the world. No mobile phone towers or land lines are required." While the spread of mobile telephony has granted access to telecommunication to many who previously had none, coverage is still not universal, and telephone calls remain prohibitively expensive in many parts of the world. To address this problem, Village Telco creates hardware and software which allow people to create and maintain their own local telephone systems. This technology "has application anywhere […] people wish to take control of their own telephone infrastructure." Village Telco systems have been successfully deployed in Jorge Gomez, Colombia; Jose Soto, Puerto Rico; Wayne Abroue, and Bo-kaap South Africa; Piracanga, Brazil; and Dili, East Timor.

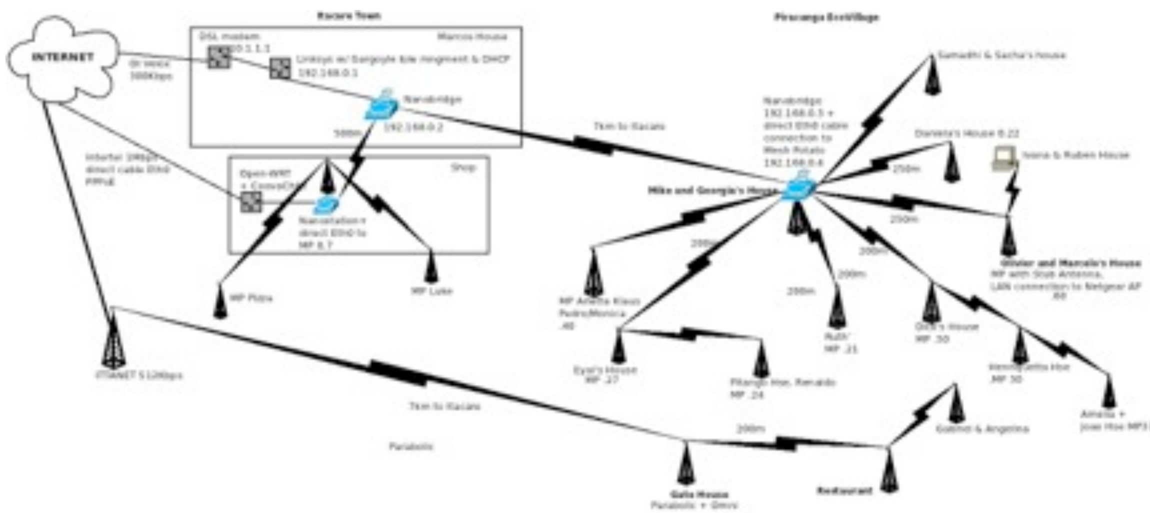

Figure 19. Diagram of a Village Telco deployment (http://www.flickr.com/photos/ssong/5011058419/sizes/l/in/photostream/ accessed Nov. 12, 2012)

Village Telcos are built around a piece of hardware called the Mesh Potato, which the Village Telco team designed to combine an inexpensive wireless access point running a mesh networking protocol with an analog telephony adapter. The Mesh Potato's unique design allows it to automatically detect other Mesh Potatoes and configure peer-to-peer networks between them and itself, allowing telephone calls without cellular towers, satellites, or landlines. This device is rugged and weather resistant, and affords users the ability to plug in any telephone handset. The port that the handset is plugged into provides power. So, if you find yourself someplace with inadequate local telephone service, simply secure some Mesh Potatoes for yourself and some of your neighbors. Plug in your old land line telephones, and you'll have created a local telephone system without involving a telephone company. Best of all, if more of your neighbors want to join up, the system you have created will scale automatically. Just add more Mesh Potatoes. I spoke to Steve Song, initiator of the Village Telco project, and former Shuttleworth Foundation fellow and researcher at the International Development Research Centre, to discuss DIY telecom infrastructure at length. My first questions were about problem formation and the design of DIY telecom.

Motivation and Problem Formation

As Steve Song explained, he was determined to do something about the high cost of telecommunications in Africa, something he has been working on for many years. According to Mr. Song, "[t]he challenge has been to increase competition in the market. It's quite a challenge because there is one particular bottleneck to entering the market and that is Spectrum, that you have to have access to Spectrum to actually become a player. Because Spectrum for mobile technology was, by definition, finite. They are only regulating certain ranges of Spectrum that worked for mobile use and that meant that the number of players in the market was necessarily limited [… this] has had a negative impact on competition because you end up with one, two, three, or four players, none of whom feel a particularly large amount of pressure to price their products aggressively or to be very innovative in how they deliver services. The people who suffer that the most, really, are the poor, who can least afford those services." [213]

[213] Steve Song, interview with Jonathan Lukens, Skype, March 3, 2012. All remaining quotations from Song come from this interview unless otherwise noted.

Around 2003, Song learned that the open source community was repurposing cheap Wifi technology to use as broadband infrastructure. Previously, Song had worked funding projects across Africa with the goal of creating a community of wireless hackers to build affordable wireless broadband. Later, he took a similar approach while a research fellow at the Shuttleworth Foundation. These experiences led him and his peers to the conclusion that there were two main barriers to the "viral uptake of low-cost wireless infrastructure."

The first was that data by itself was not going to encourage development. Voice needed to be included. According to Song, "if you just built wireless data networks that wasn't going to spur the uptake, especially in places where there wasn't adequate phone infrastructure to begin with. So we concluded that we needed a device that offered voice and data."

The second barrier was technological complexity. As Song explained, "[w]ireless networking technology, especially the unlicensed open source wireless networking technology, is robust and can do just about anything you want it to, but it is quite a devil to configure […] you have to really be a bit of a hacker to successfully configure these networks."

These two barriers informed the design of the Mesh Potato. The project had two design goals: First, support both voice and data. Second, make set-up extremely simple.

Design and Innovation

I asked Song how he felt the design of infrastructure differed from the design of another product or service. He replied that they needed to approach design differently, that they had "tried to design the technology so that the next good idea doesn't come from us." He added that they had been "modestly successful in that regard," and gave the following example: "Our switch from one generation of mesh networking technology to another […] came completely from outside the project." Here was "one person who got involved in the community […] and saw the benefits of this technology." They "just rode forward with it and developed an alternative firmware for our technology, which has gone on to become the dominant firmware." Song adds that "from a design perspective, and this is not really unique. This is really just how good open source and open standards work on the Internet."

Song goes further, and asserts that his project would not be possible without the internet facilitating the creation and distribution of open source software and hardware. This enabled his team to "draw on a broad range of open source projects, […] to discover new technologies that are perhaps more applicable to [the] project and adapt them, [and to] engage with the authors of those open-source projects." Because of this, he claims "Village Telco is not so much new technology as it is an aggregation, a novel assembly of existing technologies." For example, he adds that the Mesh Potato depends on an open source operating system designed for wireless firmware, and it uses Asterisk, a popular open source telecommunications software framework. Asterisk is typically used to build custom telecommunications applications, and can be used to build VoIP gateways and other telecommunications projects[214]. The Mesh Potato also uses open source software called B.A.T.M.A.N., which stands for Better Approach to Mobile Ad Hoc Networking[215]. B.A.T.M.A.N. is a routing protocol for mesh networks, software which allows a group of Mesh Potatoes to configure themselves into a network and reconfigure themselves if more Mesh Potatoes are added or if some are removed. In addition, the Village Telco team updated the Mesh Potato to use mesh networking technology, in which each node in the network can route information to other nodes, bypassing the intermediaries that would typically be found in non-mesh networks. This transition was simple because "none of this technology is proprietary or tied into a specific vendor." Song believes that open standards make technology more resilient. This belief is shared by many DIY infrastructure designers and open source hardware enthusiasts, and stems from the idea that open standards are more easily and quickly modified to address vulnerabilities.

Song notes that his team wasn't thinking about "crisis infrastructure," or "things like refugee or IDP [internally displaced persons] camps," even though those are potential sites for deployment. He describes his team's thinking as "surprisingly narrow in terms of how [they] were thinking about the technology." Their focus was on the prohibitive cost of access and on creating tools which would allow people to address their telecommunication problems themselves, an example of DIY infrastructure as an attempt to assuage some of the effects of radical monopoly. This focus led to the realization of the possibility that mesh wifi was a resilient alternative. In contrast to the narrow focus of the develop-

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214 "74 Open Source VoIP Apps & Resources," *VoIP Now* (Blog), last modified April 16, 2007, accessed Jan. 14, 2013, http://www.voipnow.org/2007/04/74_open_source_.html.

215 "Wiki," *Open Mesh*, last modified March 3, 2013, accessed Jan. 14, 2013, http://www.open-mesh.org/projects/open-mesh/wiki.

ment team, he admits surprise that the technology has been used in "far more prosaic ways than [they had] imagined." For example, as a simple way "to deploy a distributed PABX for their campus or for their industrial estate or for their farm."

Resilience and Complementary Technologies

Song describes himself as "a really strong believer in the importance of resilience when it comes to telecommunication and infrastructure. I believe in resilience, not just in terms of the technology we use, but in terms of having an ecology of technologies." He feels that telecommunications technologies are complementary; the goal is not for Village Telco to replace mobile service in an area that already has it, it's to add an additional service. If it were indeed a matter of replacing technologies instead of adding additional ones, that would mean less resilience.

Song uses Wifi and 3G as an example of complementary technologies. "Wifi happens to be an almost ideally complementary technology to 3G in that virtually every smartphone manufactured now comes with both wifi and 3G support. Increasingly, we see a massive offload of 3G data onto wifi networks. Certainly in the United States, something like 40 percent of all iPhone data traffic goes over wifi. We also see the massive explosion of wifi infrastructure globally. I think it will be this year or next where more wifi chip sets will ship globally than mobile phones. It's a technology that continues to get faster and cheaper." This offload is of 3G data onto wifi networks is an example of the secondary equilibria discussed earlier. In this case 3G is the primary conduit for voice and data, but the system is capable of changing states and using wifi instead. Song posits that these points of equilibrium may change positions, with wifi becoming the primary or more dominant conduit.

Song feels that this is part of a larger project of expanding the quality and range of services through DIY infrastructure. As he puts it, “I think, in many cases in telecommunications, especially in the mobile world, we’ve been flying economy. […] I think [that] if you’ve been flying economy all your life, you don’t realize it as you sit in the cramped seat, but if you have a flight in business class and try and go back to economy, it’s very noticeable. We’re unaware of the possibilities that we could be embracing in terms of low-cost messaging, low-cost voice and innovative applications.” Song believes that these possibilities are limited because operators either create or encourage situations which constrain the market.

One example he offers is that of phones running closed operating systems. He believes that launching a mobile service should be as simple as launching a web-based service, but that current operators limit these possibilities. “You can’t just hang out a shingle in the mobile world as you do on the Internet. You’ve got to negotiate for short codes, for SMS bulk services and that sort of thing with every operator in every country that you want to deliver services to. So obviously, that massively constrains scalability.” Another criticism Song has of existing mobile services is the artificially high price of SMS. “What we’ve seen, especially in Sub-Saharan Africa, is that simple technologies like SMS have huge potential, yet – they’re greater than 90 percent profit for the operators […] So there are loads of those constraints that we are not apathetic to, but just have become conditioned to accepting.”

Looking forward, Song suggests a few scenarios regarding the complementarity of wifi and 3G (or 4G, etc.). Wifi, he believes is a telecommunication infrastructure with a much greater potential than people realize. “We are scratching the surface of the potential of wifi as infrastructure. For example, [i]f you’re in New York City or London or any major urban center and you click on to connect to a wifi hot spot, […] you’ll see between 30 and 40 access points. There’s absolutely no reason that we could not be leveraging all of that access to provide a seamless infrastructure.” This would offload 3g traffic onto wifi in an on-the-fly fashion. Song explains that this would involve “changing the protocol, so that they naturally authenticate and hand off and manage billing.” According to Song, “[t]he IEEE have been working on standards for this, but it’s been incredibly slow. All of that potential exists. Wifi is incredibly powerful, but we are really just scratching the surface of its utility.”

What would such a change mean for Village Telco? According to Song “[i]t will evolve as infrastructure evolves [… R]ight now, we build in an FXS port to each mesh potato so you can plug an ordinary phone in, but as more and more mobile phones have wifi built in, we’ll probably drop the FXS port in future generations of the technology because people will just be able to connect with their smartphones. So yeah, for us it’s all about unlicensed spectrum and open standards, and I think that has global scalability.” So, Village Telco offers a method for creating a telephone system without a telephone company. By sidestepping the existing infrastructure of land line telephony, and using open hardware and software such as B.A.T.M.A.N. and the Mesh Potato to leverage innovations in networking technology, Village Telco provides an out-of-the-box solution for those with inadequate or overly expensive local phone service. So, like other DIY infrastructure projects, we can see Village Telco as a situation in which a group of people motivated by their critique of existing infrastructure are able to conceive of a design solution because they focus on infrastructure as a system. By drawing upon open source hardware and software, the team at Village Telco was able to design the Mesh Potato and attempt to perfect its deployment. In doing all of these things, Village Telco intercedes on behalf of users by occupying the void between the users and the owners and operators of the existing telephone infrastructure. Village Telco is not the only attempt to create DIY telecommunications infrastructure. In the next section, I discuss Fluid Nexus, another DIY project which adds redundancy to the existing telecommunication ecosystem.

Fluid Nexus

Like Village Telco, Fluid Nexus is a project broadening the existing ecosystem of communication technologies. Fluid Nexus is an application in development for Android phones and for Linux and Windows desktop computers which combines peer-to-peer networking with mobile phone messaging. In use, Fluid Nexus appears as a garden variety messaging application, not unlike a Twitter client. It works much differently, however, creating an ad-hoc system in which messages are exchanged from one handset to another in bucket-brigade fashion. This process removes remote intermediaries. Instead of a message being sent to a remote hub between sender and receiver as it would be with a normal SMS message, the message is handed off from one mobile device to another until it reaches its final destination. This makes point-to-point messaging between two proximate mobile devices a possibility, but also creates the possibility of mobile, peer-to-peer messaging. Thus, Fluid Nexus facilitates a new form of digital communication in which messages which are not time-critical can be sent and received without the involvement of third party intermediaries such as telephone companies.

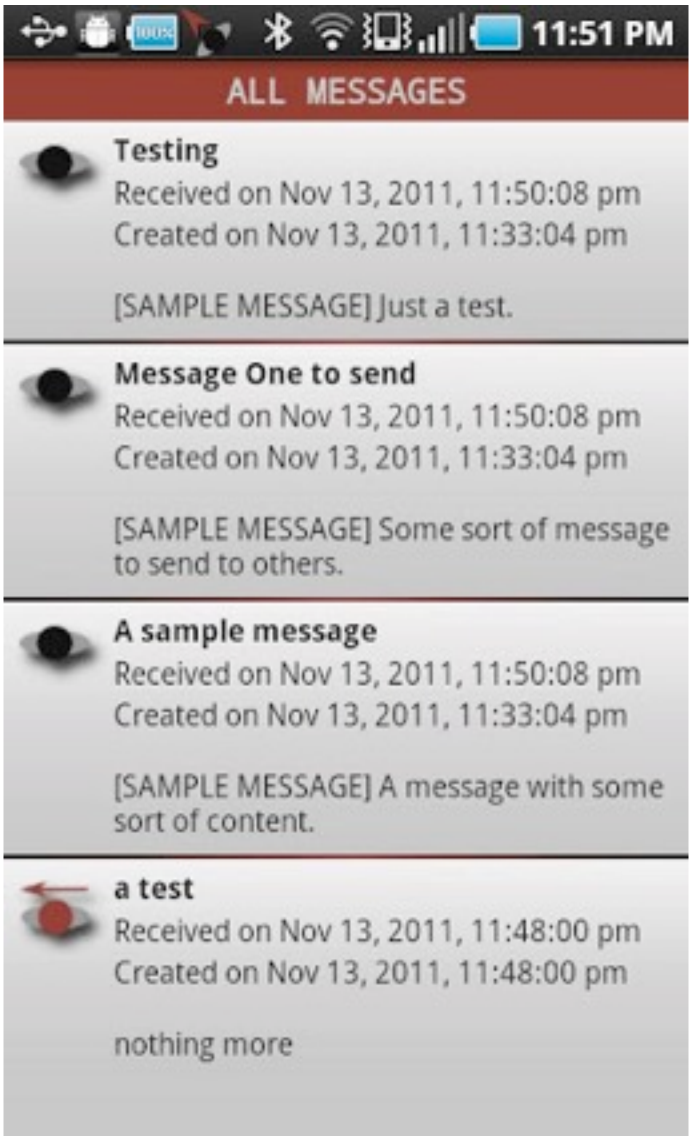

Figure 20. Screenshot of Fluid Nexus Android application (http://cdn6.droidmill.com/media/market-media/net.fluidnexus.FluidNexusAndroid_0.png, accessed Jan. 15, 2013.)

Motivation and Problem Formation

According to the Fluid Nexus website, "In the second decade of the twenty-first century, networks continue to be defined by their stable topology represented in an image or graph. Peer-to-peer technologies promised new arrangements absent centralized control, but they still rely on stationary devices. Mobile phones remain wedded to conventional network providers. Instead, the combination of peer-to-peer with mobility enables a new concept of an information transfer infrastructure that relies on fluid, temporary, ad-hoc networks. People and devices are at once implicated as mobile nodes in this network [.]" [216]

Nicholas Knouf, a programmer and creator of Fluid Nexus, explained the project through a comparison to email. "[W]e have this assumption that messages have to get through to the end. In fact, in the email specification there's nothing that says that the message actually has to make it to the end. There's no guarantee that someone's actually going to get the email, but we've become reliant on it. I think finding some way to change our relationship to these types of technologies that doesn't necessarily place so much of a burden on them in that sense would drastically change our ways of working." The degree to which failure was potentially acceptable within email led him to imagine other technological scenarios, including the "possibilities of a smaller scale infrastructure that could be connected to lots of other smaller scale infrastructures."

[216] "Concept," *Fluid Nexus*, accessed Nov. 11, 2012, https://fluidnexus.net/infos/concept.

Design and Innovation

I asked Knouf to identify some of the features of existing network infrastructure that Fluid Nexus replaces. "It's good for messaging," he replied. "You don't necessarily need to ensure that [a message] reaches a destination." Conversely, he explained, Fluid Nexus "is not good if you need to get something to a particular person very quickly." He mentions the fact that there are other groups working on projects which address that situation. Knouf adds, "[i]t's not as if I set out with a project to completely replace all of the existing infrastructure."[217] Rather, he sees it as "a replacement for certain uses of contemporary decentralized networked infrastructure, and [. . .] as part of an ecology of different projects," describing Fluid Nexus as "less monolithic than existing networked infrastructure."

Let's compare Fluid Nexus to one of these "monolithic" systems Knouf mentions. SMS, or short message service, operates through an existing pathway between a mobile phone and the nearest cellular tower. If I were to send an SMS message, it would move through this pathway to a short message service center or SMSC. The SMSC would then be responsible for routing the message to its destination, which may involve several hops through the network and a return path through a separate cellular tower to the receiver's phone. In contrast, a message sent through Fluid Nexus would not be sent to a cellular tower or handled by an SMSC. Instead, it would be sent to the closest phone running Fluid Nexus. If no such phone was found, it would be stored until one became available. Through a number of these exchanges between proximate phones, the message could

[217] Nicholas Knouf, interview with Jonathan Lukens, Skype, March 3, 2012. All remaining quotations from Knouf come from this interview unless otherwise noted.

move on to its destination, not unlike a note passed by hand. Thus, Fluid Nexus provides a messaging platform that is slower, but not reliant on existing telephone networks.

Resilience and Complementary Technologies

In this way, Fluid Nexus is another example of a redundant or complementary telecommunication infrastructure, providing resilience by creating a secondary point of equilibrium. It is a second, redundant communication channel when viewed alongside existing SMS, email, and the like. In his thinking about Fluid Nexus as a part of an ecosystem of communication possibilities, Knouf makes an analogy to Unix system tools. “Each one is really good at one particular thing. But if you combine them all together, you can do almost anything that you can imagine. I try to do as best as I can with my one part of it and hope that it can interface with these other projects as well.” Knouf sees Fluid Nexus as inspired by, existing alongside, and potentially interfacing similar telecommunications projects, such as Village Telco.

This idea of Fluid Nexus existing as part of a suite of tools informed his answer when asked if Fluid Nexus could scale up to replace existing telecommunications infrastructure. “It’s never been a project about speed […] there’s no way that this is going to get something to someone on the other side of the world within half a second. […] But if it’s something that you just want to share with someone else and you don’t really care how long it takes to get there, then yeah. [P]rojects like Fluid Nexus, in combination with other things, like the Serval Project [could] be a replacement for a network of AT&T or Orange, or what have you.” He adds “It certainly would require a different tolerance for failure, for speed." However, the possibility of replacement is not a goal in the same sense that it is with a project like Cloacina. The real goal is demonstrating "a different relationship to these types of digital networks." In order to demonstrate a different relationship, the designer has to make their audience aware of the existing relationship that they are proposing an alternative to.

Exposing Our Relationship to Infrastructure

Knouf said that exposing our relationship to the current technical infrastructure by offering up an alternative had always been on his mind when creating Fluid Nexus. In discussing the short-range communication abilities of many devices, he remarked that

> They can [already] communicate […] independently of centralized networks, because they have these short-range networking technologies in them. So why don't we just use them? [...] If I am sitting next to you in a café and I want to send you an email, why does my email have to go to I don't know how many geographic locations in the world before it gets to your machine? Why can't my email just go directly to you? [F]rom the computer science perspective, that's a very functional and efficient way of looking at things. [F]rom […] an experiential or phenomenological perspective, it's a very different way of looking at things as well, because […] [w]e can be using these things to shape the types of physical relationships we have with our devices and other people and bring them into this type of hyper-local relationship.

This shift from routing email through a remote server to using a peer-to-peer network to send messages ties into a distinctive theme of DIY infrastructure projects. Cloacina began with the goal of establishing a networked peer-to-peer system for waste management, and Feral Trade is about the literal power of a network of peers to move material.

Different Approaches

The two projects above, Village Telco and Fluid Nexus, share a number of similarities. Both provide alternatives to existing telecommunications networks, and for the designers of both, resilience becomes a design strategy. While both projects are motivated by their designers' opposition to problems with existing infrastructure, those designers also present a view of telecommunication infrastructure as an ecosystem of complementary technologies. Both projects utilize ad hoc networking in contrast to entrenched existing communication networks, and both Knouf and Song view their projects as additions to this ecosystem.

But their projects are also different in important ways. Fluid Nexus, which is still in development, is more speculative. It is intended as a proof of concept, and as an exploration of alternative network architectures. It highlights the possibilities of peer-to-peer mobile communication, and reveals the workings of current mobile communication by contrast.

While Fluid Nexus involves the design of software, Village Telco also involves the design of hardware, the Mesh Potato. As a DIY infrastructure component, the Mesh Potato is able to provide things that software alone cannot, like powered ports for existing telephones. Furthermore, in contrast to the still-developing Fluid Nexus, Village Telco has successfully created telephone systems of up to 200 Mesh Potatoes around the world including locations in Colombia, Puerto Rico, and South Africa[218].

Like Feral Trade, Fluid Nexus and Village Telco remove infrastructure from its black box and present us with an alternative of their own design. As with Feral Trade, the conception and execution of that design are dependent on a consideration of infrastructure as a system–not just in terms of its constituent components and relationships. Just as Feral Trade brought something new to our understanding of DIY infrastructure by highlighting the role of the social and the subjective in the design of logistics systems, Village Telco and Fluid Nexus show us something new as well.

Because they are both designed to add redundancy to an existing ecosystem of technologies, they offer proof of the concept of ecological resilience. They show us that the relationship between established infrastructure and DIY infrastructure can be both complementary and antagonistic, and present the design of new channels of communication as additions to an ecosystem of technologies. In the next case study we look at these ecosystems of technologies as sociotechnical landscapes, and investigate the role of design in technological change.

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[218] "3 New Village Telco Entrepreneur Profiles," *Village Telco*, accessed Jan. 15, 2013, http://villagetelco.org/2012/08/3-new-village-telco-entrepreneur-profiles/.

8. DIY SANITATION

This section provides an in-depth analysis of a DIY sanitation infrastructure project. That project, known as Cloacina, reveals an ability to challenge the radical monopoly of infrastructure through design. It also serves as an illustration of how the local innovations of DIY infrastructure may effect change on a larger scale. I begin the section with an overview of the project and the designers' motivations before discussing their challenge to radical monopoly as a change in the scope of design practice. Finally, I discuss the project within the framework of sociotechnical transitions literature in an attempt to explain how DIY infrastructure projects can interact with and alter existing infrastructure.

Cloacina is a series of projects described by its participants as "peer to peer waste processing," which attempt to use low-cost sensors and wireless technology to facilitate urban composting as a set of "self-organizing efficient services.[219]" Taking their name from the patron goddess of the Cloaca Maxima, or main artery of Rome's sewers [220], Matthew Lippincott and Molly Danielsson, the project's participants, are attempting to change what they view as harmful practices resulting from the design of sanitation infrastructure.

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[219] Molly Danielsson and Mathew Lippincott, "An Unsolicited Design Review of Composting Toilets & Composting Methods," *Cloacina*, last modified March 8, 2012, http://www.cloacina.org/files/an-unsolicited-design-review-sm.pdf.

[220] Jon C. Schladweiler, "Cloacina: Goddess of the Sewers," *Sewer History*, accessed February 20, 2013, http://www.sewerhistory.org/articles/wh_era/cloacina/cloacina.pdf.

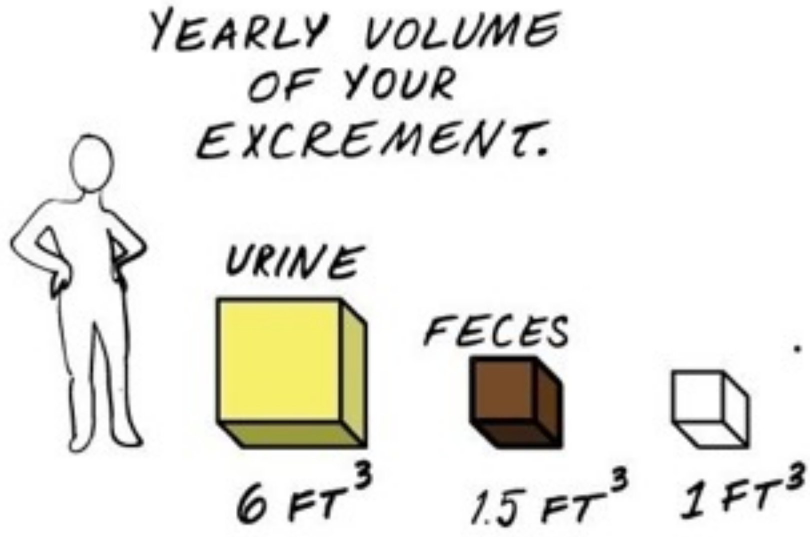

Figure 21. The yearly volume of your excrement according to Cloacina (http://www.cloacina.org/blog/wp-content/uploads/2010/02/11.jpg, accessed Nov. 13, 2012)

Figure 22. Water used by flush toilets according to Cloacina (http://www.cloacina.org/blog/wp-content/uploads/2010/02/2.jpg, accessed Nov. 13, 2012)

Figure 23. Diagram of potential use of human excrement as fertilizer (http://www.cloacina.org/blog/wp-content/uploads/2010/02/3.jpg, accessed Nov. 13, 2012)

Mathew is a director of production at The Public Laboratory, and Molly co-wrote Oregon’s building code for composting toilets, and Portland’s emergency sanitation plan. One of Cloacina’s stated design goals is to address the waste of water and phosphorus that results from the design of current sanitation infrastructure. They work toward a re-design of sanitation systems based on a different idea of which resources are abundant or scarce. Most importantly, these include water (why contaminate valuable and increasingly scarce water by using it to move waste?) and fertilizer, especially phosphorous.

As Danielsson and Lippincott argue in the studio brief of their course “Sanitation, Hygiene and Integral Technologies: legal, social, and technical breaks in the nutrient cycle," in the collaborative design master's program at the Pacific Northwest College of Art: "The provision of clean water and sewage disposal has lifted over a billion people out of the threat of deadly enteric diseases, reduced childhood mortality to its lowest levels in history, and fueled the growth of the largest cities at the center of the global economy. But sewers and septic tanks are also the center of a series of long and short-term ecological and health crises, including nitrification of groundwater, eutrophication of waterways, broken nutrient cycles, and the contamination of our food supply with micropollutants, pharmaceuticals, and heavy metals. Water-borne sanitation as practiced in the US is only feasible in wet climates and rich countries, and with Victorian-era pipes failing across the US and Europe, we are faced with reconstructing some of the most expensive pieces of public infrastructure in the history of the planet. [221]"

Danielsson and Lippincott describe their chief motivation as the reclamation of phosphorus from human excreta to replace mineable phosphorus, a resource that they feel is nearing depletion. Lippincott describes the condition: "The ability to identify mineable phosphorus is really well established. People have searched really hard, and it's pretty much all been identified. It's pretty much all being exploited, and it's going to disappear really, really, really fast. It's not like oil. They're not going to discover more of it under the Arctic and Antarctica or be able to boil it from tar sands, they're not going to be able to exploit different small parts of this resource. It's a known quantity, and it's going away. Within my lifetime I could see a complete resource collapse of our agricultural system,

[221] Molly Danielsson and Mathew Lippincott, "Sanitation, Hygiene and Integral Technologies: legal, social, and technical breaks in the nutrient cycle" (course syllabus, Pacific Northwest College of Art, Portland, OR, Fall 2012).

and it's completely feasible to prevent that." [222] Design researchers Lopes, Fam and Williams also describe "the potential value of urine as a substitute for phosphate rock, the primary component of chemical fertilizers used in agricultural food production," adding that "[m]ined phosphate rock is a rapidly depleting, finite mineral resource that underpins global food security." [223] Because phosphorus is also a pollutant, "which is costly to manage and treat," designers like Danielsson, Lippincott, and Lopes, et al., articulate a design goal of treating human urine as a resource that can be reused to facilitate agricultural production. [224]

Danielsson and Lippincott argue that when compared to other problems with existing infrastructure, phosphorus reclamation's relationship to infrastructural redesign is unique. For example, Lippincott argues "With our energy infrastructure, you could make the argument that we could discover fusion power, and with our road infrastructure, you could make the argument that we can discover a new power source or new form of synthetic fuel and it could continue to work. I'm skeptical of both of those things, but it's not completely outside possibility." However, in the case of phosphorus, he adds, "You're not going to find a new molecule to bind your cell walls together. Ain't happening." Through these examples, Lippincott is pointing to the limits of technological innovation. Technological change will not be sufficient to change entrenched patterns of use. This realization informs Cloacina's work, and can be seen in their public outreach materials such as post-

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[222] Molly Danielsson and Mathew Lippincott, interview with Jonathan Lukens, audio recording, Pioneer Courthouse Square, Portland, OR, October 17, 2011. All remaining quotations from Danielsson and Lippincott come from this interview unless otherwise noted.

[223] Abby Mellick-Lopes, Dena Fam, and Jennifer Williams, "Designing Sustainable Sanitation: Involving design in innovative, transdisciplinary research," *Design Studies* 33, no. 3. (2012): 300.

[224] Ibid. 300-301.

ers, zines, and their blog. Taken together with Cloacina's design of physical prototypes, these materials show that design is understood as a means of sociotechnical change. According to Fam, et al., writing on the challenge of re-imagining Sydney, Australia's sanitation infrastructure, "[d]esign can be understood as a practice involving the deliberate planning of sociotechnical change, yet the relational dynamics of change have not traditionally played a part in design biased toward a 'technological fix.' [225]"

DIY infrastructure projects, and Cloacina most of all, understand design as a means of sociotechnical change, and not as something as simple as the refinement of existing objects or services. As Fam, et al., describe it "[c]hange therefore cannot be brought about through technological innovations alone; it requires mutually reinforcing institutional and socio-cultural transformations. This has important implications for the relation between design and technological innovation.'" In an upcoming section, I explain the multi-level framework on sociotechnical transition and use it to explain the role of design as a means of sociotechnical change. In order to make this case, I need to describe Cloacina's work and design goals in greater detail.

Portable Sanitation

As there was already work being done with the design of residential composting toilets, and because they felt that residential change was a prohibitively expensive project, they took another approach. They explain: "You're trying to convince someone to change

[225] Dena Fam, Abby Mellick-Lopes, Juliet Willets, and Cynthia Mitchell, "The challenge of system change: an historical analysis of Sydney's sewer systems," *Design Philosophy Papers* no. 3 (2009): 1.

a very private and difficult space at expense, competing against flush toilets.” In seeking out a more accommodating design space, they thought “Nobody likes port-a-potties. The construction workers don't like using port-a-potties, concert-goers don't like using port-a-potties, and no one actually likes hauling the waste.” To that end, they began designing portable composting toilets as an alternative to common portable toilets which treat waste with chemicals.

Of course, like most design projects, this process began with a survey of existing artifacts, and thinking about their relationship with their users. In Cloacina’s case, this survey resulted in a number of presentations and small graphic design projects. In addition to the Cloacina development blog, cloacina.org, Danielsson and Lippincott produced informational posters, including “Prominent Decomposers,” “The Nitrogen Cycle,” and “Human Toilets and Urinals,” and booklets, such as “An Unsolicited design Review of Composting Toilets & Composting Methods.” These documents inform Cloacina’s design goals, and detail the sociotechnical landscape, a concept I explain in more detail later in this chapter.

Cloacina and Digital Media

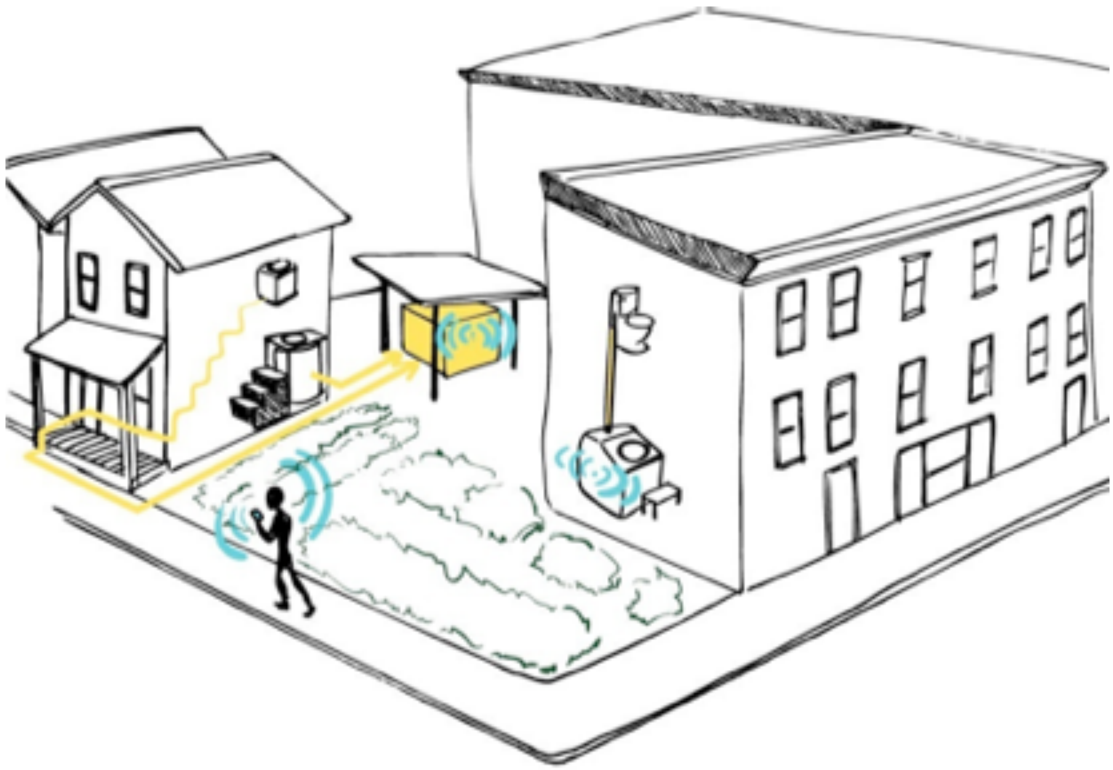

Figure 24. Illustration of mobile phone user receiving alert from Cloacina (http://www.cloacina.org/blog/wp-content/uploads/2010/02/8.jpg, accessed January 14, 2013.)

Danielsson and Lippincott's early designs attempted to incorporate several digital media components. They proposed a new infrastructure, one in which the wireless transmissions of sensors support a logistic of waste management that removes the need for large systems of underground pipes flushed with water. For instance, sensors could detect waste matter and, as an additional example of the procedural capacity of the computer, determine and broadcast its status–whether it is inert or a possible disease vector. For example, concerned citizens could sign up to receive an alert from a sensor equipped DIY public urinal informing them that it needed to be emptied. After someone responded that they were on the way, the urinal could sterilize its contents using ultraviolet light. The participant could then transport its contents to a public park or community garden were it could serve as valuable fertilizer.

Danielsson and Lippincott prototyped compost monitoring systems with the ultimate goal of developing "a networked sensor platform for navigating the social and legal obstacles to locally cycling organic matter,[226]" which would close "the loop between composting toilets and gardens by monitoring the composting process to verify the destruction of pathogens, reassure neighbors and eaters, and placate regulators." They felt that digital sensing technologies would allow them to confirm the safety of contentious biological matter, and that they could leverage modern advances in logistics to address waste management problems.

[226] Molly Danielsson, "Fighting the Flush: Metropolis Next Generation Competition," *Cloacina Development Blog*, last modified February 4, 2010 (10:23 p.m.), http://www.cloacina.org/blog/2010/02/fighting-the-flush-metropolis-next-generation-competition.

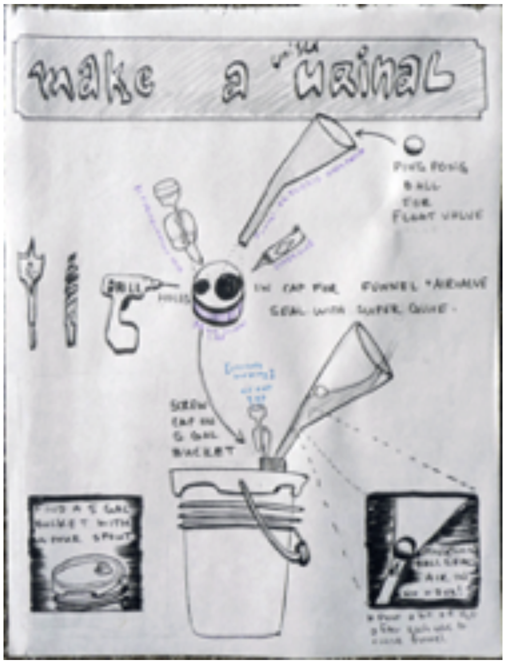

Figure 25. DIY Urinal construction diagram and sensor attached to mobile phone (http://www.cloacina.org/blog/wp-content/uploads/2010/04/P1010925_c_sm.png, and http://www.cloacina.org/blog/wp-content/uploads/2010/06/inside-the-system.png, both accessed January 14, 2013.)

In drawing upon the procedural and participatory capacities of the computer, Danielsson and Lippincott attempted to replace a physical network of pipes carrying water with an informational network routing the people who would route the waste. Of course, since this system still requires manual labor – at least in carrying inert waste from a holding tank within a composting toilet to a vehicle, or from a vehicle to agricultural land where the waste will be used as fertilizer–this means increased human exposure to waste. Even if the waste matter is rendered harmless, this increased human interaction with it alters the ontological separation between technology and society and between society and the natural environment as a commodity.

In Danielsson and Lippincott's own words, they "are creating an alternative municipal waste disposal system that replaces mechanical power and centralization with composting and information […] [their] networked system will [… bring] human talent and electronic systems together to guide and watch over the biological processes that transform waste." [227] They are arguing that the capacities of digital media allow them to reconfigure their existing waste disposal system. Their success or failure highlights the role of digital media in the reconfiguration of municipal infrastructure. As they wrote in the document "DIY R&D for Neighborhood-Scale Sanitation: Composting Greenhouses & Environmental Monitoring," "Dry sanitation, ecological sanitation, is a logistics problem. Luckily the modern world is great at logistics.[…] By applying networked management, electronic sensors, and containerization to the problem of our excrement, we can make dry

[227] Molly Danielsson and Mathew Lippincott, "Overview," *Cloacina*, accessed February 21, 2012, http://www.cloacina.org/index.php?/overview/.

sanitation far more sanitary, painless, and reasonable than sewer systems. If we can drive down the cost of monitoring both collection containers and compost, mistakes can be minimized and tracked, and expertise can be applied remotely.[… a] system of sensors, transporters, and performance benchmarks can coordinate the sanitization and cycling of our organic matter. [228]"

[228] Molly Danielsson and Mathew Lippincott, "DIY R&D for Neighborhood-Scale Sanitation: Composting Greenhouses & Environmental Monitoring," *Cloacina Development Blog*, accessed Nov. 15, 2012, http://www.cloacina.org/blog/wp-content/uploads/2011/01/Booklet-Justmonitoring-sm.pdf.

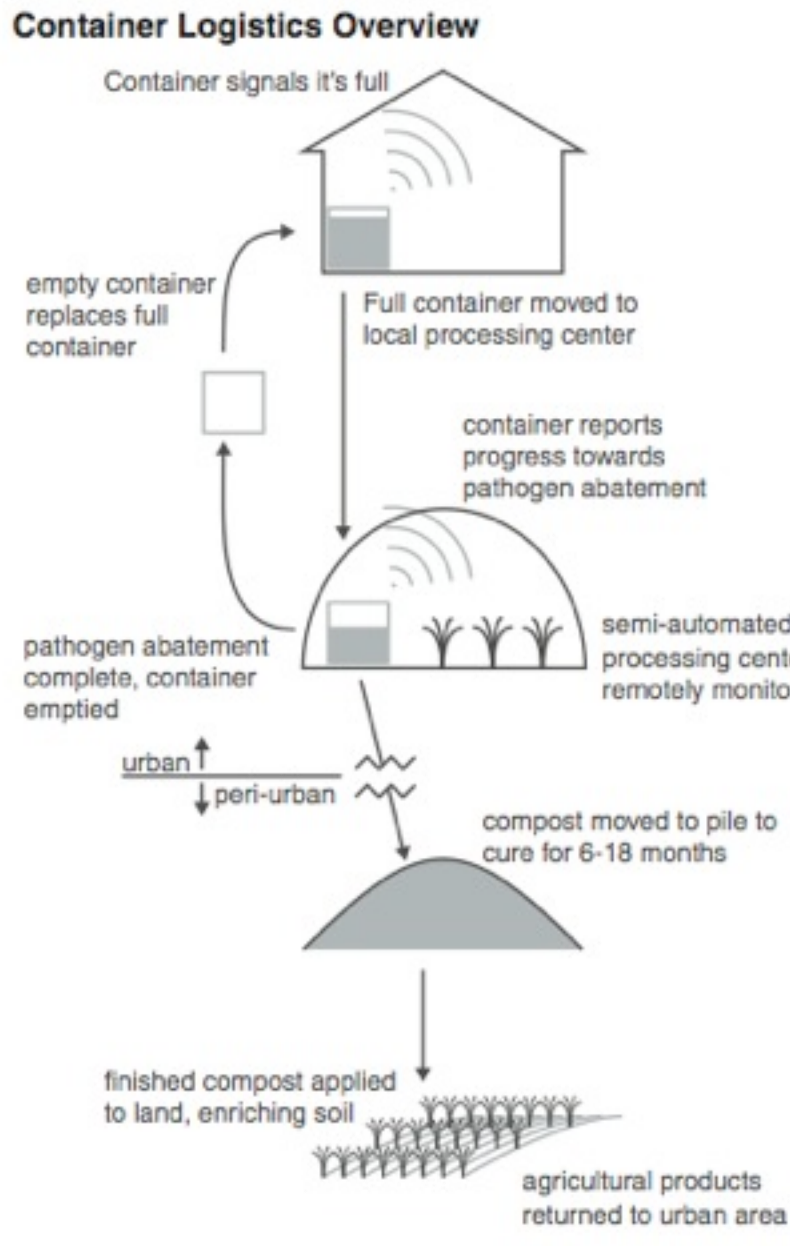

Figure 26. Container Logistics Overview

(http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CDAQFjAA&url=http%3A%2F%2Fwww.cloacina.org%2Fblog%2Fwp-content%2Fuploads%2F2011%2F01%2FBooklet-Justmonitoring-sm.pdf&ei=xlKlULSLF8bJqgGM34C4Dw&usg=AFQjCNGWuEZ0RwMooub6XbpFeAlus5JFwg accessed Nov. 15, 2012 p.4)

Danielsson and Lippincott saw this as part of the design of a larger system of closed-loop technologies in which human waste would be composted and that compost would be used to support local community agriculture. Part of this initiative was SensorHub. Described at length in the aforementioned document, SensorHub was an attempt at a repository for data collected by sensors installed in compost containers, and was created after Danielsson, Lippincott, and their collaborators found similar systems inappropriate for their ends. In contrast to other systems, such as Pachube and SensorServer, SensorHub was designed around SMS and email, lessening the need for smartphones and internet connections. In time, SensorHub, weatherproofing sensors, and Cloacina's other digital media design endeavors began to take a back seat as Danielsson and Lippincott prepared for a large-scale field test of their portable composting toilets.

Cloacina's Initial Deployment

In October of 2011, I observed this initial deployment at an event called the Northwest Permaculture Convergence. Cloacina was contracted for approximately $1200 to provide sanitation for a three day outdoor event, which would have otherwise hired a company providing regular portable chemical toilets. This event was attended by approximately three hundred people. Over the space of three days, Danielsson, Lippincott, their students in Pacific Northwest College of Art's collaborative design master's program, and a handful of volunteers addressed construction and maintenance factors as they arose, and collected observations on their designs from users and each other. This period of observation, as well as subsequent interviews, made me appreciate Cloacina as an attempt to challenge radical monopoly through design.

Fig 27. toilet stalls from Cloacina field test. (Personal photograph. October 15, 2011.)

Fig 28. toilet from Cloacina field test (Personal photograph. October 15, 2011.)

This challenge is evident in their design goals. Danielsson and Lippincott envision a system based on voluntary labor. They believe that “sanitation as part of a technological package that is reproducible has to involve things that people will voluntarily do.” They argue that our current infrastructure is based on non-voluntary or coercive tasks, and they would like to capture the same benefits without coercion. This echoes Ivan Illich’s assessment that radical monopoly “exists where a major tool rules out natural competence. Radical monopoly imposes compulsory consumption and thereby restricts personal autonomy.”

In discussing Cloacina’s design goals, Lippincott is fond of historical examples. He argued that explorers like Magellan traveled the world equipped with everything they needed to repair and reproduce the technologies that they depended on. For example, a ship would carry its own blacksmith and carpenter. This allowed Magellan’s crew to re-build their boats in Indonesia before returning home. He laments the fact that that type of encapsulated tool set is gone, saying “when your equipment breaks in the middle of no-where–you don't have any ability to remake it. You don't have any ability to sustain it.” Compare this with Illich’s characterization of radical monopoly: “The establishment of radical monopoly happens when people give up their native ability to do what they can do for themselves and for each other, in exchange for something ‘better’ that can be done for them only by a major tool. Radical monopoly reflects the industrial institutionalization of values. It substitutes the standard package for the personal response. [229]”

So, Cloacina’s design goals challenge radical monopoly conceptually, and their design work is a challenge to the radical monopoly of sanitation infrastructure, but what can other designers and design researchers learn from these challenges? In the next section I discuss these difficulties in challenging radical monopoly through design by drawing two points from Cloacina’s design practice.

[229] Ivan Illich, *Tools for Convivality* (New York: Harper & Row, 1973), 54.

Challenging Radical Monopoly

Cloacina's work is an attempt to challenge radical monopoly through the practice of design. It suggests that large technical systems are not immutable, and is informed by a belief that very real change can happen in a short span of time. Danielsson and Lippincott argue that this belief is historically grounded: "Most cities in the world were all sewered up in the course of a very short period of time." So when people argue that the redesign of infrastructure is impossible, they need to recall that "the public at large was convinced to pay for the most expensive pieces of public infrastructure in the history of mankind–our water and sewer systems–and the fact that that happened in such a short period of time."

They went on to argue that this means "There is a significant historical precedent for a massive infrastructural shift in a short time scale:[…] People in cities were almost universally using the toilet in buckets, and they were flushing their toilets within 15 years." So, why is it not possible that they could be using a different system 15 years from now?

Fam, et al., discuss this transformation in a historical analysis of Sydney's sewer systems. As they put it, "[t]he transformation of sanitation from the use of cesspools to sewer systems was a radical change and can be characterized as a transition whereby both the technical and socio-cultural dimensions of the system changed drastically." [230] They describe this transition as creating "a 'seamless web' of mutual dependency. [231]" According to Illich, this dependency can only be broken if the public realizes alternatives to it. In his

[230] Dena Fam, Abby Mellick-Lopes, Juliet Willets, and Cynthia Mitchell, "The challenge of system change: an historical analysis of Sydney's sewer systems," *Design Philosophy Papers* no. 3 (2009): 2.

[231] Ibid.

words “The cost of radical monopoly is already borne by the public and will be broken only if the public realizes that it would be better off paying the costs of ending the monopoly than by continuing to pay for its maintenance.[232]” In the language of sociotechnical systems scholarship, “any deliberate change toward a system of sustainable sanitation will require a nuanced understanding of both the social and technical dimensions that contribute to change.”[233] Cloacina’s designs are an attempt to articulate the social and technical dimensions of an alternative system, and the cost of transitioning from the current one. Danielsson and Lippincott offer a critique of what they feel are the myths of the existing system.

Existing Monopolies are Valorized

In my interview with Danielsson and Lippincott, they argue that a critical mass of established designs can become valorized, making historical design decisions more difficult to question. They feel that their designs challenge the way that people imagine and perceive the function and benefits of current sanitation infrastructure.

For example, they mention the “gross factor,” in which people are reluctant to use a composting toilet because they feel they will be exposed to excrement and germs, adding that most people do not evaluate the degree to which those things are present in their current situation. “Their toilet backs up and overflows into their bathroom about once a year,

[232] Ivan Illich. *Tools for Convivality*. 1973. p 56

[233] Dena Fam, Abby Mellick-Lopes, Juliet Willets, and Cynthia Mitchell, “The challenge of system change: an historical analysis of Sydney’s sewer systems,” *Design Philosophy Papers* no. 3 (2009): 2. internal citations omitted

and, in a normal bathroom there's a toilet brush with microscopic amounts of feces dripping water onto the floor and a plunger right next to it doing the exact same thing."

They also feel that this unquestioning faith in the validity of past design decisions has lent itself to a sort of revisionist history. Another way of explaining this is to take the phrase that "history is written by the winners," and rephrase it as "history is written by the designs with the largest user base." For example, Danielsson and Lippincott are resistant to the "idea that the flush toilet has a historical role in the prevention of human disease." Referring to the work of architectural historian Anthony Sutcliffe, they claim that "If you look at statistics on deaths in Paris–one of the first cities to completely sewer up–their sewers prevented deaths from cholera but increased deaths from typhoid. There was no related reduction in enteric diseases[234]" until after the introduction of plumbed and chlorinated water. "Essentially," they add, "it's not about preventing excrement from entering the water;[…] it's about poisoning the water so that the excrement can't kill you. That's really the only effective part of our modern sanitation system that's actually doing something to prevent diseases."

In actuality, they argue, sewers were designed to prevent miasmas. Miasmas are pockets of alleged "bad air" which were blamed for diseases. The sanitation infrastructure we have today was designed in accordance with this now-discredited theory of disease, prior to the acceptance of germ theory. According to Fam, et al., "[s]ewers were constructed at the same time as miasma theory was coming under scrutiny from new scientific evidence on 'germs.' Therefore the timing of contextual factors, such as the belief in

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[234] Anthony Sutcliffe, *The Autumn of Central Paris: the Defeat of Town Planning 1850-1970* (Montreal: McGill-Queens University Press, 1971), 103-104, 106.

miasma theory, was influential in the outcome of the sanitary revolution and the technologies adopted. This reveals the significance of developing a historical perspective on the evolution of slow moving, large technical systems such as sanitation. Contextual factors and beliefs (such as miasma theory) have contributed to embedding centralized technology, infrastructure and social practices within western society even though these beliefs and understandings may be irrelevant and outdated by today's standards." [235] Much of the work of the designer challenging existing infrastructure involves design as a critique of this sort of valorization. According to Lippincott, "The biggest problem in the field right now is that people can't imagine a different system, and they have no experience with anything different. If all we did was help establish enough publicly accessible case studies so that this stuff was on people's radar, I would feel pretty happy with that."

It remains to be seen if Cloacina will succeed or fail in redesigning sanitation infrastructure or even in provoking discussion about the myriad issues affected by its design. Nonetheless, it is a valuable project to investigate because it brings the otherwise invisible force of infrastructure to light, and reveals the influence of past designs on future designs. As designers become increasingly aware of the complexity of forces their designs influence and are subject to, projects which employ design to trace and challenge the often invisible constraints of those forces allow us to reassess the space of design action and its results.

Cloacina's work reveals a change in the scope of design practice, with new actors designing systems and services that were previously within the domain of small groups of

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[235] Dena Fam, Abby Mellick-Lopes, Juliet Willets, and Cynthia Mitchell, "The challenge of system change: an historical analysis of Sydney's sewer systems," *Design Philosophy Papers* no. 3 (2009): 2. Internal citations omitted.

experts. Today's design decisions involve long-established social and technological relationships–the aggregate result of many previous design decisions and their effects. DIY infrastructure projects detail overlooked attributes of these decisions.

The Possibility of Individual Action

Writing on the sometimes stultifying perception of infrastructure as monolithic, Edwards describes "large, force-amplifying systems that connect people and institutions across large scales of space and time […] paragons of modernity understood as a condition of subjection to systems, bureaucracies, hardware, and panoptic power" and the "sense that infrastructures are beyond the control of individuals, small groups, or even perhaps of any form of social action, and that they exert power of their own. [236]" This characterization highlights two of the more significant possibilities for DIY infrastructure. First, they may represent a possible systemic change wrought by new technologies; in the case of DIY infrastructure, we may see that individuals and small groups DO have the capacity to "exert power on their own [237]." Alternately, DIY infrastructures may be quixotic projects–not capable of initiating systemic change, but still valuable because they reveal the properties of infrastructure, the ways that infrastructure is an embodiment of political authority, and the contingent nature of modern life as the product of large interconnected technical systems.

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[236] Paul N. Edwards, "Infrastructure and Modernity: Force, Time, and Social Organization in the History of Sociotechnical Systems." In *Modernity and Technology*, eds. Thomas J. Misa, Philip Brey and Andrew Feenberg (Cambridge: The MIT Press, 2003), 220-222.

[237] Ibid.

Put broadly, "individuals and small, spontaneously organized social groups shape and alter infrastructures. In redeploying emerging infrastructures to their own ends, users participate in creating versions of modernity. Here too, the form and function of infrastructures shift and change over time, albeit for very different reasons than at the macro scale.[238]" Here, we can see a motive for users participating in the political project of infrastructure. Next, we need to focus on opportunity as well as motive and consider the way that mutually constituted shifts in technical capabilities and political will inform DIY infrastructure projects.

As I have discussed, sustainability–notably sustainable phosphorus–is of one of Cloacina's design goals. Cloacina's work fills a void articulated by Victor Margolin in his 1998 article "Design for a Sustainable World." Margolin wrote that in terms of sustainability, "Design discourse has too easily supported a rhetoric of idealism that is at odds with the reality of daily practice. The second is a crisis of imagination. Too few examples of projects that are socially directed serve to stimulate or inspire designers. While such projects do exist, they are, for the most part, closed out of academic design courses and professional publications.[239]" Cloacina is an example of this. While it may not be noted in academic or commercial design literature, it stands out as an example of daily practice directed towards sustainable and non-commercial ends. Moreover, the properties of infrastructure that Cloacina unveils help us contextualize the landscape of our daily lives, revealing the complex interactions that the designers of a sustainable future must contend

[238] Ibid. 222.

[239] Victor Margolin, "Design for a Sustainable World," *Design Issues* 14, no. 2 (1998): 89.

with. This leads directly into an understanding of the role of design in sociotechnical transitions.

Sociotechnical Transitions

It can be difficult for designers to understand the relationship of their practice to infrastructure or other large entrenched systems. While projects such as Cloacina raise a host of significant issues for designers, it remains to be seen how DIY infrastructure projects might initiate broader systemic change. How might the work of today's designers influence the grey panoply of path dependence, obduracy, monopoly? How can the objects and systems we design extend their reach into our daily lives? The first place to look for answers is in a body of literature discussing the multi-level perspective on transitions in sociotechnical systems.

This multi-level perspective, or MLP, explains change as the result of interaction between processes at three levels. Frank Geels, a scholar of sociotechnical change, and his contemporaries have developed and refined the MLP and applied it to cases including the transition from cesspools to sewer systems in the Netherlands [240], body disposal practices in the UK [241] , and the Dutch electricity system [242]. After providing a brief overview of the

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[240] Frank Geels and René Kemp, "Dynamics in sociotechnical systems: Typology of change processes and contrasting case studies," *Technology in Society* 29, no. 4 (2007): 446.

[241] Adrian Monaghan, "Conceptual niche management of grassroots innovation for sustainability: The case of body disposal practices in the UK," *Technological Forecasting & Social Change: an International Journal* 76, no. 8 (2009): 1–18.

[242] Geert Verbong and Frank Geels, "The ongoing energy transition: Lessons from a sociotechnical, multi-level analysis of the Dutch electricity system (1960–2004)," *Energy Policy* 35, no. 2 (2007): 1025–1037.

MLP, I will explain its significance to DIY infrastructure and share some thoughts on what it means for design at large.

There are three nested levels within the MLP. The broadest level is that of the sociotechnical landscape. This level is the domain of "macro-economics, deep cultural patterns, [and] macro-political developments." Changes at this level typically take place over the course of decades. The second, or meso-level, is called the sociotechnical regime. This level includes entrenched technical artifacts and designed systems, as well as standards and protocols, cognitive routines, regulations, "sunk investments in machines," infrastructures, and path dependence. The third level is that of technological niches. This is the level at which "radical novelties emerge." According to Geels and Schot, "[t]hese novelties are initially unstable sociotechnical configurations with low performance. [...] Niches act as 'incubation rooms' protecting novelties against mainstream market selection." These niches address a need raised by Victor Margolin in his 1998 article "Design for a Sustainable World," where he argued that design thinking needed to be decoupled from its role in shaping objects for the market in order for design to help achieve sustainability.

The concept of technological niches also complements scholarship of the development of infrastructure. Thomas Hughes writes on that subject in "The Evolution of Large Technological Systems." As he says:

> Development is the phase in which the social construction of technology becomes clear. During the transformation of the invention into an innovation, inventor-entrepreneurs and their associates embody in their invention economic, political,

> and social characteristics that it needs for survival in the use world. The invention changes from a relatively simple idea that can function in an environment no more complex than can be constituted in the mind of the inventors to a system that can function in an environment permeated by various factors and forces. In order to do this, the inventor-entrepreneur constructs experimental, or test, environments that become succesively more complex and more like the use world that the system will encounter on innovation[243].

We can understand Hughes' discussion of designs embodying "economic, political and social characteristics" needed for survival, as matching a description of those qualities that innovations at the technological niche level would need to resist the forces of the sociotechnical landscape. At the same time, Hughes refers to the iterative development of test environments or conditions, evoking the nature of design without ever using the term.

DIY infrastructure projects occupy the technological niche level while being conscious and critical of the constraints of the sociotechnical regime. For example, the Cloacina project involves the redesign of sanitation systems and components within a protected niche. The decision to focus on portable toilets instead of permanent ones is an attempt to find a suitable space for iteration insulated from the sociotechnical regime level. If Cloacina's prototypes were brought to market in their current state, they would face considerable resistance at the sociotechnical regime level from regulators, established

[243] Thomas Park Hughes, "The Evolution of Large Technological Systems," in *The Social Construction of Technological Systems*, ed. Wiebe Bijker, Thomas P. Hughes, and Trevor Pinch (Cambridge: The MIT Press, 1987), 63.

businesses, and established practices and preferences. The radical monopoly of infrastructure occupies the two upper levels of the MLP.

How do these "radical novelties" move upward from the protected design space of the technological niche and change things in the upper levels of sociotechnical regime and sociotechnical landscape? How might the work of Cloacina, Feral Trade, or other DIY infrastructure designers leave the protected level of the technological niche and make any substantive change? Geels explains such transitions as occurring at the interface of the three levels of the MLP at times when the states of the individual levels align in particular ways. For example, innovations at the technological niche level may gain traction because of improvements on previous designs or support from external groups. At the same time, problems at the sociotechnical landscape level destabilize the sociotechnical regime, creating the opportunity for niche level designs to proliferate. [244] So, the ability of a novel design to break through into the upper levels of the MLP is contingent on both its improvements on existing designs in use at the sociotechnical regime level and on problems at that level causing disruptions in the sociotechnical landscape. Together, these factors provide the opportunity for the new designs to challenge the old.

What sorts of disruptions to the sociotechnical landscape provide opportunities for niche level designs to take root? Geels discusses several, including changes in cultural values, technical problems which force actors to seek out new solutions, negative externalities such as health and safety impacts, changing user preferences, and competition

[244] Victor Margolin, "Design for a Sustainable World," *Design Issues* 14, no. 2 (1998): 90.

between firms which open them up to innovations from the niche level in order to gain an advantage over their competitors. [245]

Though the multi-level perspective highlights this critical alignment between niche technologies and disruptions of the sociotechnical landscape, it is important to note that this is not necessarily momentary. Writing on long-term transformative change, Grin, Rotmans, and Schot characterize breakthroughs, which “may be relatively fast” as taking around ten years, while “innovation journeys through which new sociotechnical systems gradually emerge usually take much longer,” or around twenty to thirty years. [246]While they describe transitions as “radical shifts from one configuration to another,” they specify that “[t]he term ‘radical’ refers to the scope of change, not to its speed. [247]” Grin, Rotmans, and Schot cite Braudel’s analysis of history through multiple scales of time, concluding that the heuristics of “multi-causality, co-evolution, lateral thinking, anti-reductionism, patterns, context and the use of different time scales,” all benefit the study of transitions. [248]

Thinking of design as a process unfolding across decades or more may be foreign to many designers who are concerned with product cycles or other more immediate deadlines. Thinking of design at this scale can be stultifying, and its necessity is something that can make DIY infrastructure seem so quixotic. At the same time, it is something that

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[245] Frank Geels, “From sectoral systems of innovation to sociotechnical systems: Insights about dynamics and change from sociology and institutional theory,” *Research Policy* 33, nos. 6-7 (2004): 914.

[246] John Grin, Jan Rotmans and Johan Schot in Collaboration with Frank Geels and Derk Loorbach, “Transitions to Sustainable Development,” in *New Directions in the Study of Long Term Transformative Change* (New York: Routledge, 2010), 11.

[247] Ibid.

[248] Ibid. 15.

DIY infrastructure design shares with sustainable design. According to Fam, et al., "[t]his basic explanation of how sociotechnical systems change is interesting to consider in regard to design's potential for contributing to a transition toward sustainability." They add that design can be understood as operating across the levels of the MLP, "particularly in terms of the co-evolution of artifacts and human practices.[249]" For example, designers are typically responsible for incremental change at the meso, or sociotechnical regime level of the MLP. In this way, design can be seen as "reinforcing existing practices and stabilizing existing systems.[250]" From the critic's point of view, this makes design part of the problem. Design augments existing sociotechnical relationships, making the adoption of alternatives more difficult.[251] For example, the design of flush toilets which use less water can make it harder to make the case for completely waterless systems.

Fam, et al., have this to say about the relationship between the design of the flush toilet and the design of sanitation infrastructure at large: "The 'flush toilet' is not an isolated artifact but rather part of a much broader sociotechnical system comprising of sewerage pipes, waste water treatment plants, water supply, extensive capital infrastructure investment, rules and regulations dictating health standards on treatment and cultural habits of use, perception-driven practices, not to mention engineering practices, production processes, and skills which have become embedded in western society over the last century – […] the 'sociotechnical regime'[252]. In spite of the complex relationship of the artifact

249 Dena Fam, Abby Mellick-Lopes, Juliet Willets, and Cynthia Mitchell, "The challenge of system change: an historical analysis of Sydney's sewer systems," *Design Philosophy Papers* no. 3 (2009): 2.

250 Ibid.

251 Ibid.

252 Ibid.11-12.

with the regime, the design of the flush toilet predisposes it to be treated as an isolated artifact, supporting a cultural disconnection in relation to water use and waste production.[253]" This means that designers attempting to alter the sociotechnical regime need to understand problems at that level (the level of sanitation infrastructure), not just at the level of the artifact (the toilet).

Activists may attempt to address issues at the regime level. For example, activists concerned with the same issues as Cloacina may focus on changing building codes, or addressing other impediments. Cloacina, in focusing on building a functioning system, operates at the technological niche level instead. This allows development and refinement of prototypes in a protected space until the problems identified at the sociotechnical regime and sociotechnical landscape levels provide the opportunity for a technological transition.

So, while everyday resistance to infrastructure's radical monopoly may be as simple as bicycling or as invisible as infrastructure itself, DIY infrastructure projects are a noteworthy challenge because they are pursued through design. Echoing Victor Margolin's assertion that "When design is not limited to material products, design can intervene within organizations and situations in a greater number of ways,[254]" Cloacina employs design to critique and reapply design's own regulatory force.

[253] Ibid.

[254] Victor Margolin, "Global expansion or global equilibrium? Design and the World Situation," *Design Issues* 12, no.2 (1996): 31.

9. CONCLUSION

In this document, I have explained the significance of infrastructure and its relationship to design and to digital media. Infrastructure embodies political authority through regulation and resource allocation. It both constrains and informs future designs, and designers contend with those constraints even if they are unaware of them. Digital media scholarship often focuses on establishing a series of properties of digital media artifacts and using those properties to analyze specific artifacts. As infrastructure is extended and augmented by sensors and other digital devices, the properties of digital media, as articulated by Murray and Manovich, are increasingly applicable to its study. In this final chapter, I will review the shared characteristics of DIY infrastructure projects and recall key points for designers from each of the case studies I presented previously.

DIY infrastructure design projects involve thinking about–and designing–infrastructure as a system and not just in terms of its constituent components or relationships. Of course, such considerations are not entirely foreign to the design of infrastructure, but when surveying the landscape of design disciplines, few projects involve the conspicuous consideration of the creation of such systems. Kate Rich's goals for Feral Trade extend beyond the design of a database, its interface, or the experience of its users. Rich is attempting to design those things, but they are part of a large whole and exist as a document of and an interface to a social network, a logistics system, and a work of art. Village

Telco and Fluid Nexus are not simply attempts to design new telecommunications hardware and software; they are attempts to design new ways of supporting mediated communication and increase the robustness of the telecommunications ecosystem. Cloacina is not just an attempt to build a different type of portable toilet; it is part of an incremental approach to redesigning sanitation as a system, including our attitudes.

Of course, new entries into the technological landscape benefit from the analysis of the technologies they seek to replace. In designing new infrastructure, DIY infrastructure projects unveil infrastructure's operation, removing it from the black box our habits and assumptions have placed it in. This is called infrastructural inversion. Feral Trade reveals the social element of infrastructure. Village Telco and Fluid Nexus reveal the hierarchical structure of existing telephone and messaging networks. Cloacina reveals the workings of our sanitation systems and the problems they create.

DIY infrastructure projects are not the work of paid professionals, and are not primarily designed for profit. Instead, the designers of DIY infrastructure are motivated by problems that they have identified in existing infrastructure. For example, Kate Rich of Feral Trade is motivated by a desire to reveal the social component of logistics systems and test the load-bearing capacity of social networks. The Village Telco team is motivated by a desire to provide an affordable alternative telephone service. Nick Knouf of Fluid Nexus wants to explore the capabilities of peer-to-peer messaging. Danielsson and Lippincott of Cloacina are working to develop systems for alleviating the depletion of mineable phosphorus and lessening the waste and contamination of water.

In addition to these shared traits, all of the projects I have detailed above expose something crucial on their own. Feral Trade exposes the role of the social and the subjective in the design of logistics systems. For designers, Feral Trade stands as an example of the significance of social networks, personal transactions, and conflicts with regulators. Village Telco and Fluid Nexus show us that the relationship between established infrastructure and DIY infrastructure can be both complementary and antagonistic, and present the design of new channels of communication as additions to an ecosystem of technologies. They show designers of future objects and systems, infrastructural or otherwise, the complexity of positioning their new designs relative to established ones. Finally, Cloacina provides us with an example of a way that DIY infrastructure projects or other designs might scale up and effect lasting sociotechnical change.

DIY infrastructure projects are paragons of the reciprocal influences of digital media, infrastructure and design. Their study highlights the relationship between design and DIY as practices, digital media studies as a way of understanding designed artifacts and the relationships they enable, and the many ways that infrastructure is fundamental to our daily lives. The properties of digital media inform the process of DIY infrastructure's design, including facilitating DIY practice, and shape the sociotechnical landscape that DIY infrastructure projects are attempting to change.

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